THE IDEALS OF ENGINEERING ARCHITECTURE

CHARLES EVAN FOWLER

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-8 FEB 1996		

This book may be recalled
before the above date

The Ideals of Engineering Architecture

Fowler

THE AUTHOR'S WRITINGS

THE COFFERDAM PROCESS FOR PIERS
ORDINARY FOUNDATIONS
SUB-AQUEOUS FOUNDATIONS
ENGINEERING AND BUILDING FOUNDATIONS
MASONRY FOR BRIDGES
TIMBER IN BRIDGE CONSTRUCTION
LAW AND BUSINESS OF ENGINEERING AND CONTRACTING
ENGINEERING STUDIES
CATHEDRAL OF ST. JOHN THE DIVINE
CONTRACTS AND SPECIFICATIONS
AMERICAN BRIDGE SHOP METHODS
MACHINERY IN BRIDGE ERECTION
STEEL ROOFS AND BUILDINGS
CORROSION OF IRON AND STEEL
SEA PORT STUDIES
WORLD PORTS AND HARBOR DATA
SAN FRANCISCO-OAKLAND BRIDGE
RATIONALE OF BRIDGE DESIGN
ECONOMICS OF STEEL ARCHES
NIAGARA RAILWAY ARCH BRIDGE
HURRICANE ENGINEERING
DETROIT-WINDSOR SUSPENSION BRIDGE
ENDURANCE AND BEAUTY OF STEEL BRIDGES
NAPOLEON SUPERMAN (IN PRESS)
NAPOLEON'S CIVIC WORK (IN PRESS)
THE IDEALS OF ENGINEERING ARCHITECTURE


American Society of Civil Engineers
Phebe Hobson Fowler 1838-1928
Engineering Architecture Award
"When Types Which Are the Mind's Creation,
The Hand to Perfect Form Hath Wrought."

The Knoxville Tennessee River Bridge Fowler

THE IDEALS OF ENGINEERING ARCHITECTURE

CHARLES EVAN FOWLER
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MEMBER SOCIETY OF TERMINAL ENGINEERS

"Whoever thinks a faultless piece to see,
Thinks what ne'er was, nor is, nor e'er shall be."
* * * * * * * * *
"Content if hence th' unlearn'd their wants may view,
The learn'd reflect on what before they knew."
—*Pope.*

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THE IDEALS OF ENGINEERING ARCHITECTURE

By Charles Evan Fowler

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DEDICATED TO MY MOTHER

PHEBE HOBSON FOWLER

TO WHOSE INSPIRATION AND ENCOURAGEMENT
THIS BOOK IS DUE

AND TO THE
STUDENT CHAPTERS
OF THE
AMERICAN SOCIETY OF CIVIL ENGINEERS

"The mighty pyramids of stone,
That wedge-like cleave the desert air,
When nearer seen and better known,
Are but gigantic flights of stair."

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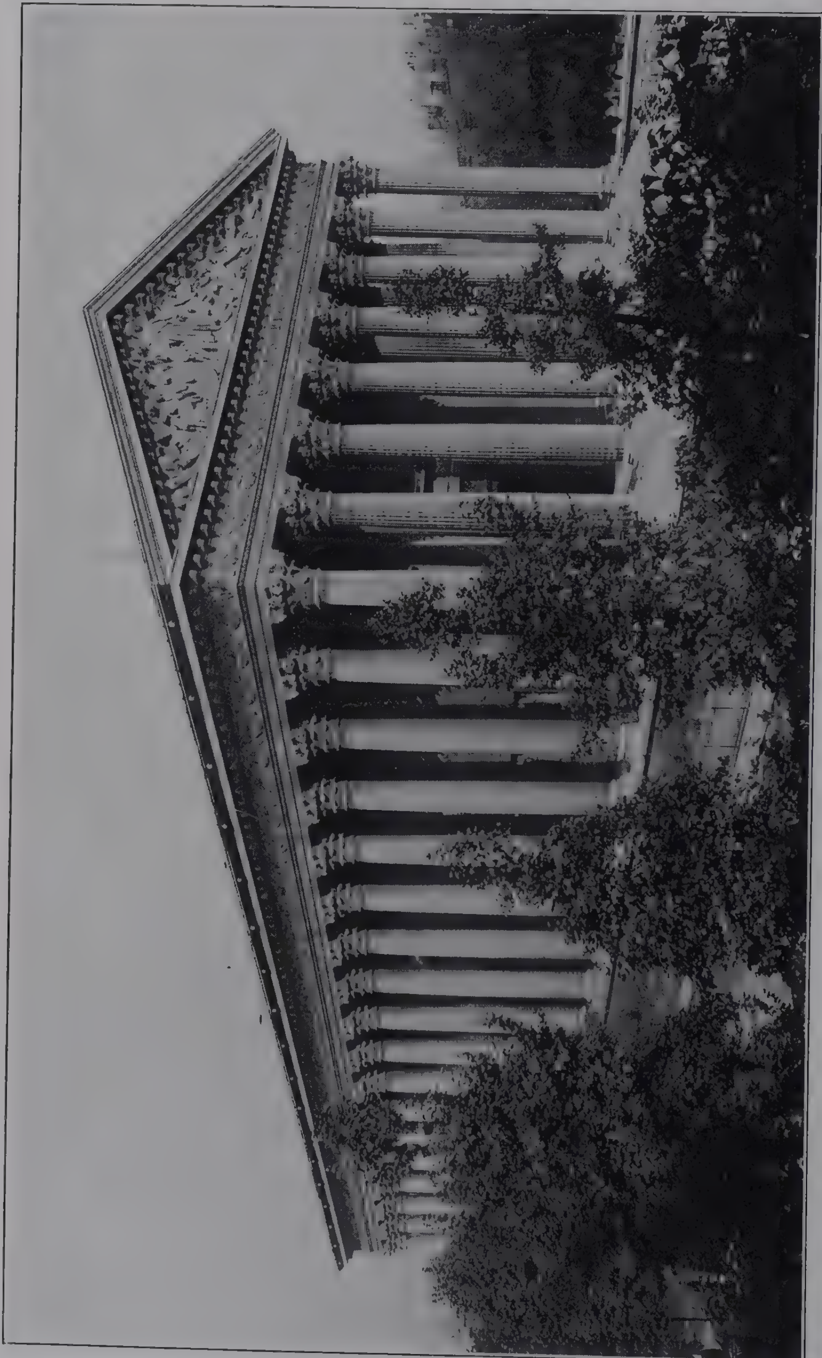
INTRODUCTION

IDEAS AND AIMS

The subject of Engineering Architecture as one of the Arts has been but scantily treated by engineering and architectural writers, and by none in an extensive or comprehensive manner. The nearly twenty years during which the author donated lectures to the University of Washington at Seattle, developed a trend of thought along somewhat systematic lines, tending towards a real system for the treatment of engineering structures by means of basic architectural design, as against the mere decoration of such structures with beautiful ornaments borrowed from the storehouse of the architect, which too often have been entirely inappropriate. There are other instances of engineering structures having been decorated by special consultants, who did not or would not understand the underlying principles or features which made one class of decoration not positively inappropriate, but which in most cases produced a very bizarre or unpleasing result. The consultants who decorated an engineering structure some years ago, stated that anything which looked right was strong enough. Fortunately the engineers stood by to see that such a fallacious principle was not applied with disastrous results.

The part taken by the structural engineer in the new architecture of America was stated by Claude Bragdon in a review "Towards a New Architecture," in a recent number of the Outlook. "The architect," he said, "is usually a reconstructive archaeologist in difficulties, of foreign extraction and only partially extracted, believing that all the good songs have been sung and all the true words spoken, and that—

> Art stopped short
> In the cultivated court
> Of the Empress Josephine,



THE MADELEINE PARIS NAPOLEON'S TEMPLE OF GLORY

because no American architect except Sullivan has invented a form, feature, or ornament which post-dates the Empire of the first Napoleon.

"Now what is the reason for all this—for these are good men and true, however misguiding and misguided? The answer is: The tyranny of Europe and the past over their imaginations, as fostered by the false education to which they have been subjected. Sullivan alone seems to have survived it, but he paled his ineffectual fires in the rising sun of Burnham and Company, who so much more fully shared, and better understood, the captain-of-industry psychology. The engineer, forced to abandon all aid and comfort from the Old World and the past, by reason of the newness of his material (steel) and the novelty of his problems, and therefore subject to no educational malpractice, has succeeded where the architect, taught only to lie and to steal, has failed. All that we can truly and unreservedly admire in American commercial architecture is its inspired engineering—and to the degree to which the architect has had a hand in that he is worthy of all praise. Those vast parallelepipedons of brick, those sky-piercing peopled obelisks and towers, those marble-lined, lighted catacombs—everything, in point of fact, that in terms of three-dimensional inclosure ministers to our modernity—we owe more to the engineer than to the architect.

"Regret has been expressed in certain quarters that the new Holland Vehicular Tunnel under the Hudson is without any architectural expression or embellishment whatsoever—its entrance a mere hole in the wall. This on the face of it is ridiculous, yet I, for one, am reconciled, because that entrance would in all probability be given the form of a Roman triumphal arch, flanked by two Corinthian columns, or perhaps four—or peradventure six—and I am sick unto death of Corinthian columns. The other day I visited the architectural department of an eminent university, and what did I find? Lusty young undergraduates bent over drawing-boards engaged in flanking 'An Entrance to a Garage' with Corinthian columns. I made the remark, 'They ought to burn all the books in your architectural library, and then you couldn't do a thing so gauche as that!' But one young meanie hazarded the question, 'Your own among them?' A hit, a very palpable hit!

THE BOURSE PARIS NAPOLEON'S STOCK EXCHANGE

"Let it not be thought that I subscribe to the heterodoxy embodied in a remark made by a well-known captain of industry: 'Engineering is all that there is to architecture, anyway.' No! a thousand times no! The engineer, as a rule, knows nothing and cares less for those very spatial rhythms,

AMERICAN PARABOLIC PYRAMIDAL
1100 FT. HIGH 112 STORIES FOWLER

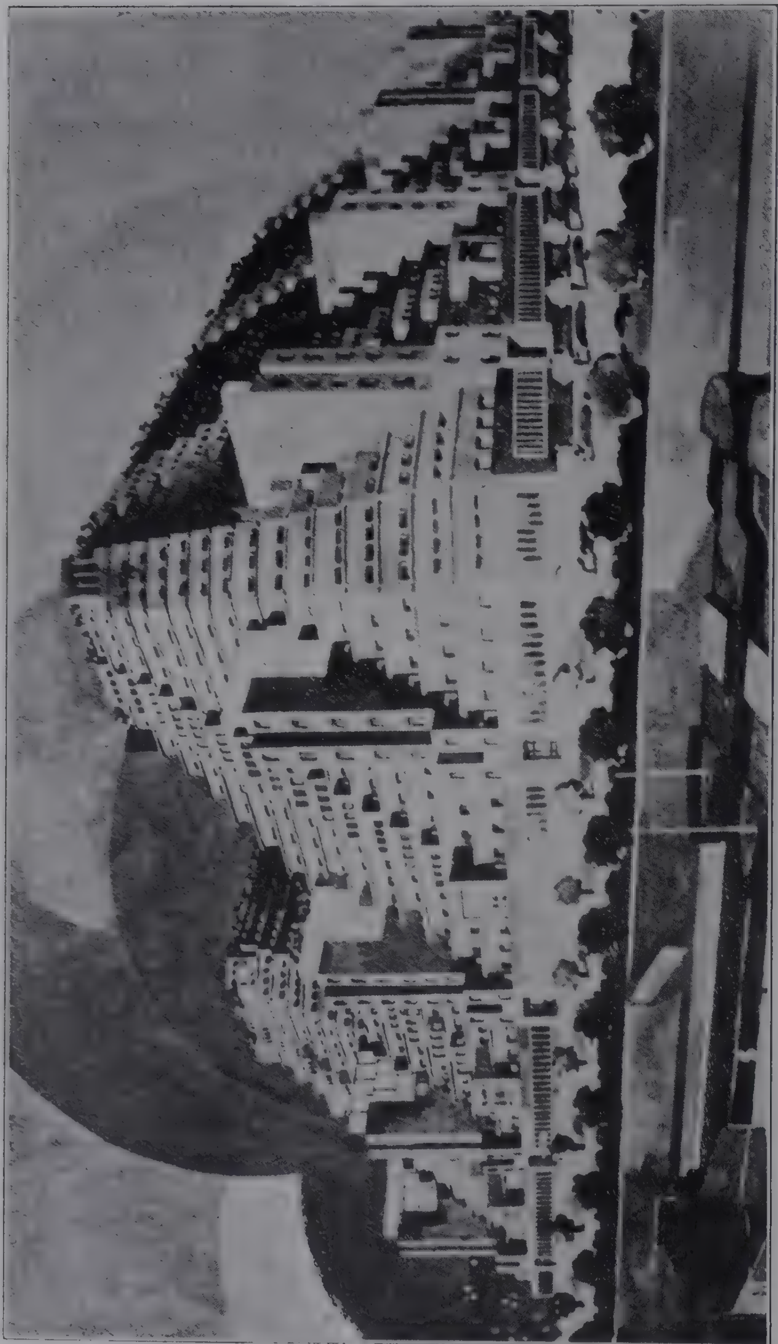
co-ordinations, correspondences, which by a curious paradox his own mathematics are always leading him toward and pointing out. Nor does he know anything of those eloquent juxtapositions of forms and colors, those revelations of the qualities of different materials, and of the quality of sunlight

Equitable Building New York American Perpendicular

itself, in the recognition of which architecture constitutes itself as a 'fine' art. Engineering is the raw drama, and the architect is the skilled dramatist; his work is to dramatize the engineering, to tell what the building is doing, what it is for, and what it is about. And if he be a good architect he will do this with a skill and eloquence of which the engineer, however accomplished, will be utterly incapable. (?) No, the trouble with the architect is that he is trying to tell another and a different story, or to tell his story sentimentally

PAGODA AT BANGKOK

and romantically, in an alien or dead language, instead of simply, straightforwardly, and sincerely in a language all can understand. This is the task to which, in the end of all ends, he will have to address himself. Greece, Rome, Renaissance Italy, and mediaeval Europe will not help him. If he plays about in those fair and ruined gardens, he is only wasting his time. What he requires is a different training



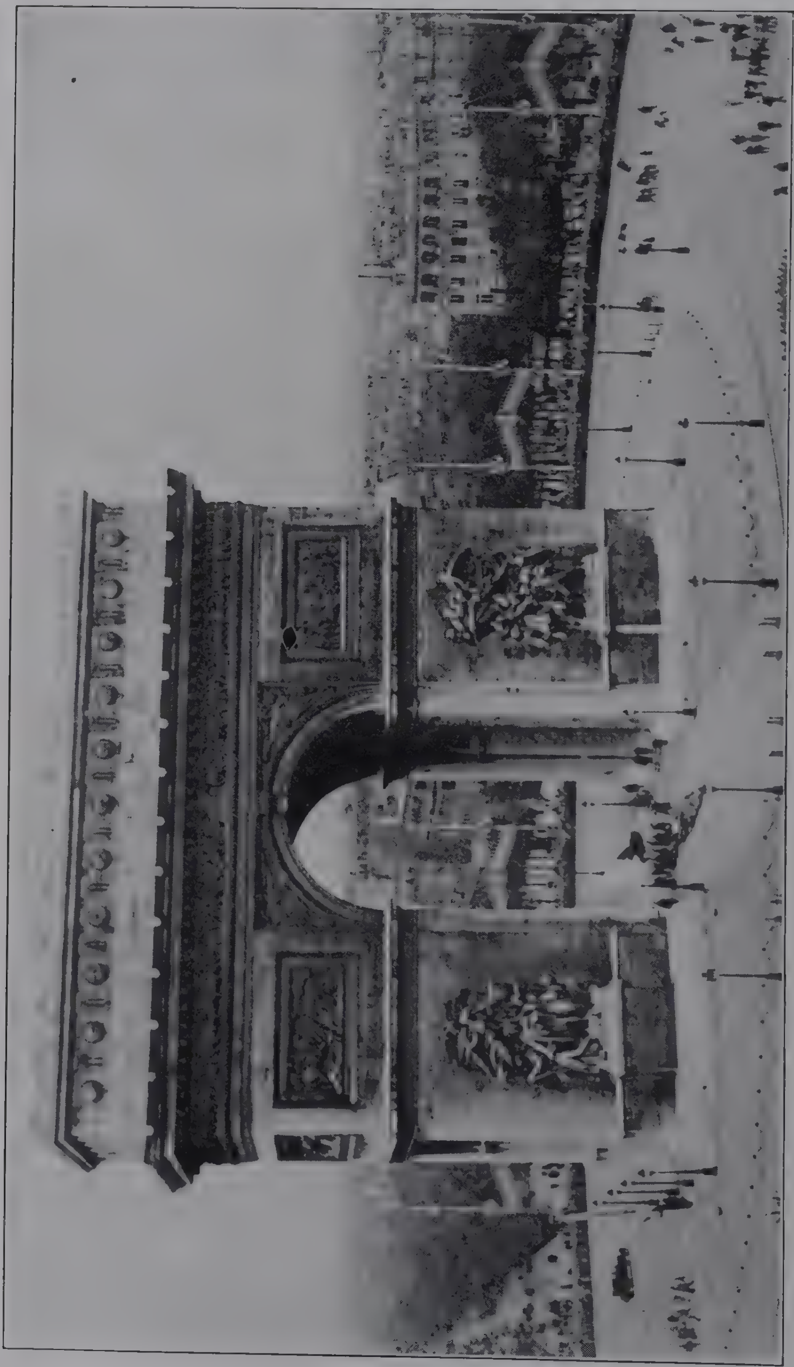
AMERICAN PYRAMIDAL A FRENCH CONCEPTION

and point of view entirely; he should do, not what the engineer has done, but as he has done."

The engineer as at present educated and trained, is thus relegated by Bragdon, to the ranks of a mere technician, and very properly too, as art for art's sake has been left out of his curriculum. Yet he and he alone is responsible for the new world styles which are in most cases not "new world symphonies," but must be named the American Perpendicular or American Pyramidal styles. The artistic urge must be awakened in the engineer by a proper education under a revised curriculum, for however much this may be needed for the betterment of our engineering, it is more necessary as a development of the spiritual in man the engineer, that he may enjoy life to the full, and build more beautiful structures

RIALTO BRIDGE MICHELANGELO

that will assist in the spiritual and aesthetic development of the human race. The remark made by C. Shaler Smith, the dean of American bridge engineers, to one of his assistants—"Most bridges are examples of what not to do"—must be remembered by anyone who wishes to attain to high rank in his profession. It is to be feared that in most cases we feel that, "in the long run, the average sense of the many is better for the many than the best sense of any one man." There is a right and a wrong; most engineers attain neither, in the hope they are right and the fear they are wrong.



Arc de Triomphe de L'Etoile Paris

We need not care whether a detail is Byzantine, Greek, Roman, Gothic, Renaissance, or American, if it is of the proper proportion, harmonizes with the other details, with the structure, and helps in forming an entirely pleasing ensemble. The Gothic arch was Persian before it was Gothic. Our structure may be similar to a work of architecture, in that it is neo-classic, but who would say that for this reason the

St. John's Cathedral Walker Design

Rathhaus of Cologne, or the Hotel de Ville in Antwerp, are not good pieces of art?

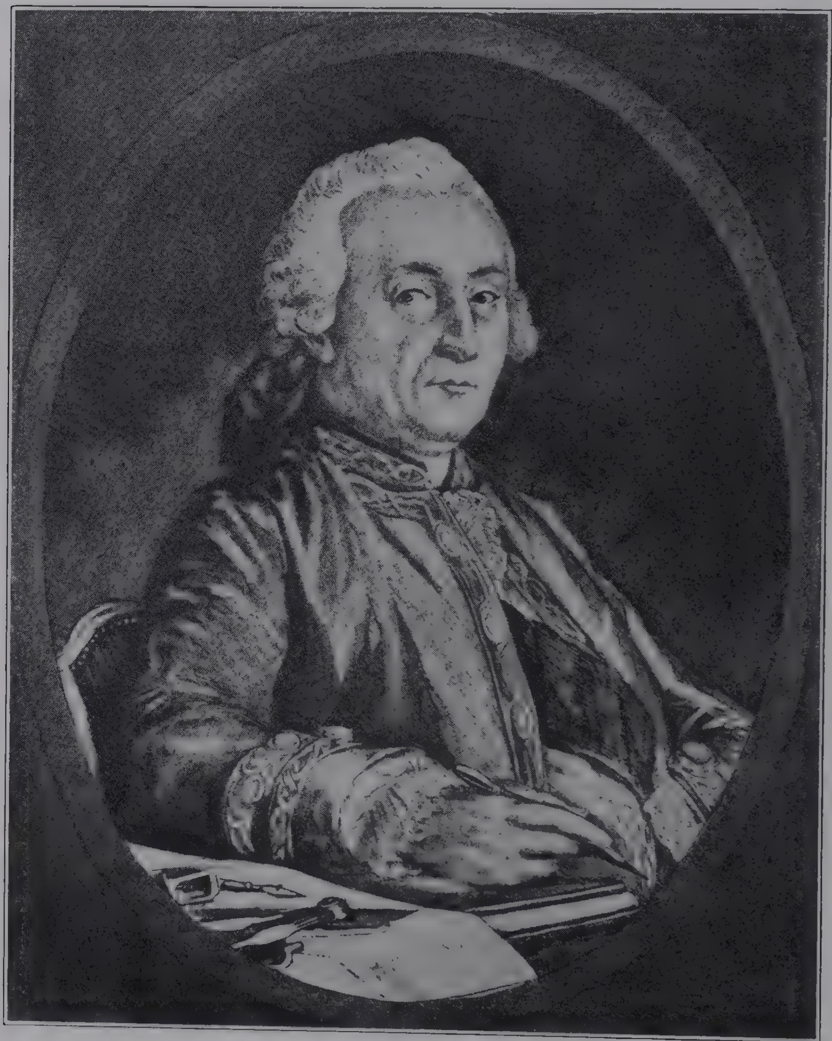
The Taj Mahal in Agra is an example of the wonderful design and construction, such as has been done in the world without servile copying having been found necessary. The Emperor Shah Jahan erected it in 1632 A. D. as a tomb for his favorite wife Mumtaz Mahal and he was buried there as

The Taj Mahal at Agra

well. It was designed by Ustad Isa a native of the region, and while it is asserted that a French architect was the real designer, this has never been proven. Fergusson describes this white marble building in his "History of Architecture." "This building is an early example of that system of inlaying with precious stones which became the great characteristic of the style of the Moghuls after the death of Akbar. All the spandrils of the Taj, all the angles and more important architectural details, are heightened by being inlaid with precious stones such as agates, bloodstones, jaspers and the like. These are combined in wreaths, scrolls and frets, as exquisite in design as they are beautiful in colour, and relieved by the pure white marble in which they are inlaid, they form the most beautiful and precious style of ornament ever adopted in architecture. It is lavishly bestowed on the tombs themselves and the screens which surround them, but more sparingly introduced on the mosque that forms one wing of the Taj, and on the fountains and surrounding buildings. The judgment, indeed, with which this style of ornament is apportioned to the various parts, is almost as remarkable as the ornament itself, and conveys a high idea of the taste and skill of the architects of this age."

The engineer has been blamed and praised for his high steel buildings, but the end is not yet. The design by the author for a Union Station building 1100 feet high with 112 stories, is the highest so far seriously proposed. The various sections of from 12 to 18 stories have the top corners to the tip of the finial lying in vertical parabolic curves, to give a subtle element of beauty, somewhat akin to the graceful curve of a classic column. The construction of the interior comprises a great fan dome over the concourse, with elevators around the sides, and a battery at the center to reach the tower stories. The outline is in general like that of the great Pagoda at Bangkok, the unknown designer of which, was more daring if possible than those of the present, considering the materials available. The architecture of Siam was largely concerned with the design of religious building, and was a derivation from that of the more ancient Khmers, who were among the finest designers of this period in art.

The design made for St. John's Cathedral in New York City by the late J. Bernard Walker, Civil Engineer and Editor



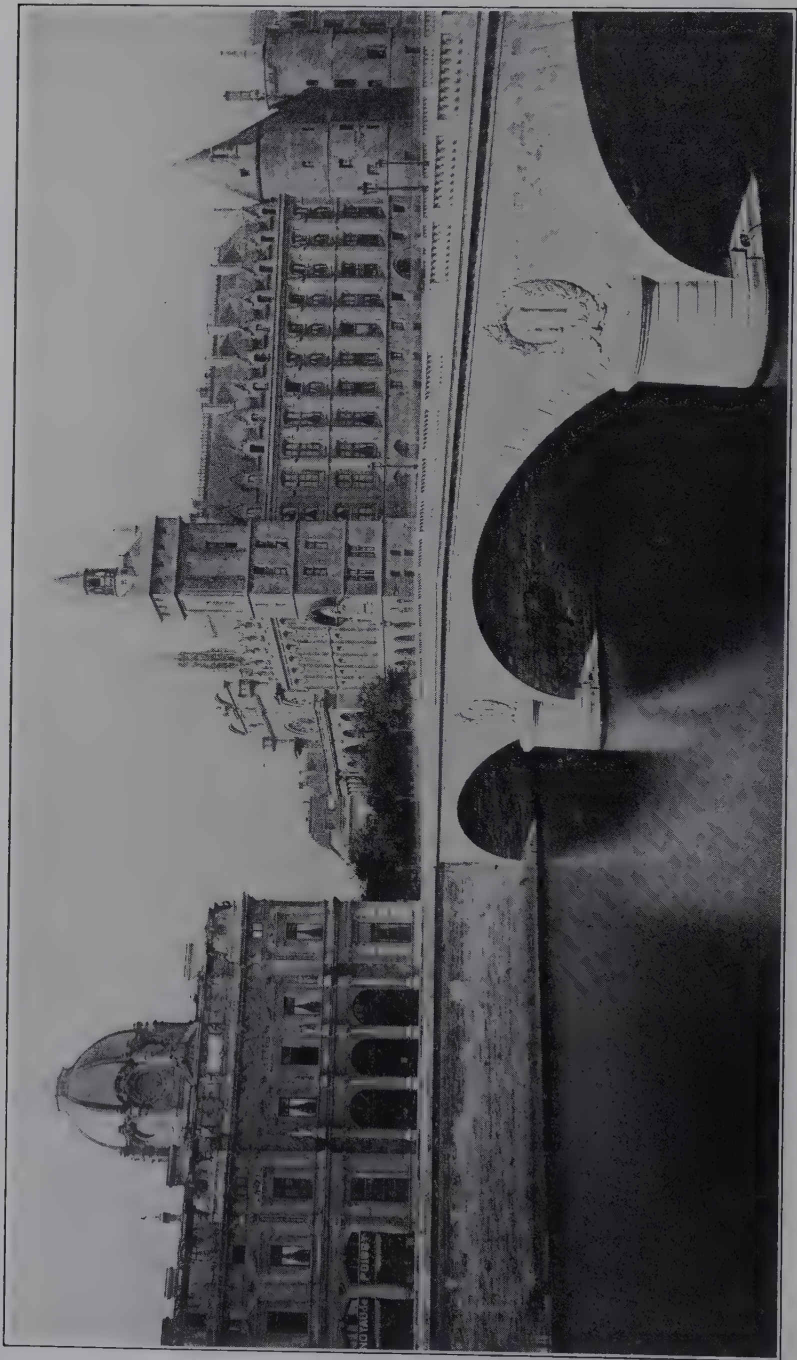
Jean Rodolphe Perronet

of the Scientific American, is another proof that engineers can design along artistic lines, if they seriously undertake such tasks, when imbued with the love of English cathedrals as the designer was, to the extent of making their study his hobby. He died while touring England to visit them once more.

The Arc de Triomphe was begun by Napoleon and completed under Louis Philippe, as a memorial to the Grande Armee of the Emperor. Fashioned upon the Roman idea of the Triumphal Arch, it far surpasses anything of the sort in the world, in size, proportions, and beauty. The details are of the most exquisite sculpture and each part is in splendid harmony with the entire arch, which dominates the view from any direction in this part of Paris. The design in its parts and in the ensemble, bespeaks an originality which raises it far above a mere copy.

The Bourse, the Madeleine, the Arc de Triomphe, and the Pont au Change are examples of the Empire classic revival and of the Napoleonic bridge architecture, that show clearly the beauties of such designs, and while they are now much decried, not infrequently is it necessary for the architect and engineer of today to emulate Percier and Fontaine, and the Engineers of Des Ponts et Chaussees of the First Empire, when it is desirable to create a work of imposing character. There is too much in present day architecture and engineering that has no artistic basis, and which is too often absolutely repulsive, to decry the copyists of any period in too emphatic a manner.

The diagonals or latticing in a bridge are sometimes unpleasing, and at other times in some other structure, not unpleasing. They probably originated with the savage, who used vines or fibre to form diagonals for his primitive structures. The farmer of today still uses ropes or wire for similar purposes, but as yet neither diagonal bridge members, nor the garden trellis, have been accorded a niche among architectural styles. The engineer, for some scores of years, has calculated his diagonals, and used them in his design because he believed they were necessary, no matter how incongruous they appeared. Now we know how to provide for secondary stresses, and can often omit the diagonals whenever a more pleasing structure will result.



Pont au Change River Seine Paris

The curved lines of the suspension bridge and of the arch are inherently beautiful, and simplicity is best illustrated in its pleasantest features in bridges of this type with no decorations or embellishments of any kind. However, we must not overlook the fact that even a chaste design may be much improved in appearance by the use or addition of appropriate and harmonious details or decorations. The suspension bridge seems sadly designed where the towers are not properly completed by a parapet or attic story for those of stone, and

ARCH OF MUD BRICKS BABYLON 4000 B. C.

perhaps finials and crestings for those of steel. The arch is made more beautiful by molded work in the arch ring, by the use of appropriate medallions at the key stone, by the careful embellishment of the spandrels or spandrel arches, and lastly by the use of well designed and ornamented parapets and parapet railings.

The aim of this book is to set forth some of those things that ought to be done, and some of those things which ought not to be done in designing engineering works, to make of

them pleasing structures if not works of engineering architecture, which as a system can result only from long years of education, study, and development.

We must remember that there is nothing really in common between the architecture of buildings and the artistic design of most engineering structures. The lack of any attempt at artistic design in the Williamsburg suspension bridge is deplorable; the failure to complete the towers of the Brooklyn Bridge is deplorable; the attempt at an artistic design for the Manhattan bridge produced a structure which is only not unpleasing; but in the Hell Gate arch we have a beautiful structure which is also of great simplicity. It is not often given to man or to the engineer, to attain nearly to perfection, seldom more than once; but by careful study and thought, we can obviate very many flagrant violations of the artistic in the design of our engineering structures.

"Chisel in hand stood a sculptor boy,
With his marble block before him,
And his face lit up with a smile of joy
As an angel dream passed o'er him.

"Sculptors of life are we as we stand,
With our lives uncarved before us;
Waiting the hour when at God's command,
Our life dream passes o'er us.

"If we carve it then on the yielding stone,
With marks of deep incision,
Its heavenly beauty shall be our own,
Our lives that angel vision."

CHAPTER I.

HISTORY OF ENGINEERING DESIGN. RELATION BETWEEN ENGINEERING AND ARCHITECTURE.

The history of engineering dates back to practically the same remote period in the past, as the beginnings of Architecture. The seven wonders of the ancient world well illustrate the relationship between the engineer and the architect as far in the distant past as history is fairly authentic, when the architect was the engineer, or when his superintendent carried out the engineering phases of construction.

The best authenticated list of the Seven Wonders of the Ancient World is that given by Edgar J. Banks, the noted Babylonian and Egyptian explorer.

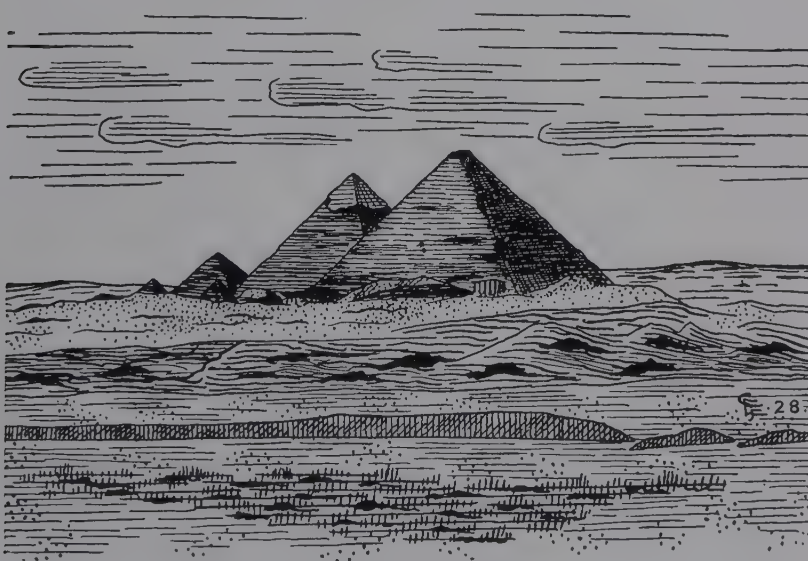
1. The Great Pyramid of Cheops.
   Constructed about 2900 B. C. by King Khufu or Cheops.
2. The Walls of Babylon.
   Constructed about 600 B. C. by Nebuchadnezzar.
3. The Statue of Zeus at Olympia.
   Constructed about 470 B. C. by the Sculptor Phidias.
4. The Temple of Diana or Artemis.
   Constructed about 350 B. C. by the Architect Chersiphron.
5. The Tomb of Mausolus.
   Constructed about 350 B. C. by Queen Artemisia, his wife.
6. The Colossus of Rhodes.
   Constructed about 280 B. C. by the Architect Chares.
7. The Pharos of Alexandria.
   Constructed about 247 B. C. by Ptolemy Soter, and Philadelphus.

The great pyramids of Egypt are practically works of engineering construction in their entirety, as the designs

DETAIL OF GREAT PYRAMID

made about 5000 years ago are so simple, that there was little work for the architects, whoever they may have been. The Great Pyramid of Cheops or Khufu has a base of 756 feet square, a height of 481 feet, and a top 32 feet 8 inches square, instead of the original 16 feet 6 inches before the polished granite facing on the sides and top was removed. There is no record as to whether it was crowned with a statue or any other sort of finial. The first great work of the constructor,

who employed 300,000 men for thirty years, and whom he fed largely on radishes, onions, and garlic, was to prepare the great foundation bed. The granite was quarried in Syene, about 700 miles away in Upper Egypt, and the limestone for the body of the pyramid at Mokattam, just across the river Nile. The greatest feat of all was to raise and place all the 2,300,000 stones of an average weight of two and a half tons. There is no proof that they were raised by a series of ingenious timber levers on each step, as stated by some writers, and it would seem most likely that a huge earth slope was piled up, and the stone dragged up with ropes and man power. Besides

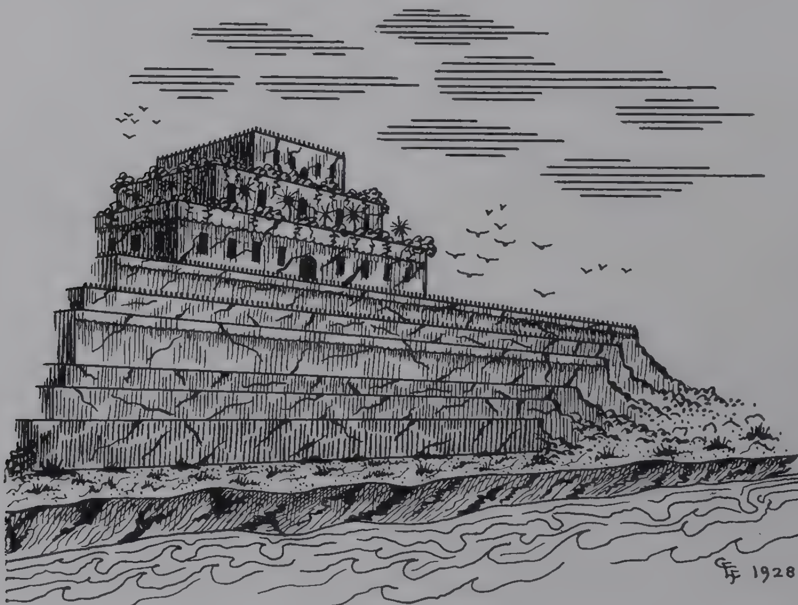


THE PYRAMIDS OF EGYPT

their food the workmen or slaves got only their scanty clothes for wages, so it seems reasonable that the total cost of this great pile of stone was only about six hundred talents of silver or a million dollars in our money. Certain it is that this great engineering work was well done, efficiently and economically executed, and there was glory enough for both engineers and architects.

The Walls of Babylon, the second wonder of the world, constructed by King Nebuchadnezzar, were remarkable both for length and height. The circuit of the outer walls was

eleven miles, and the heighth about 164 feet, while the walls protecting the palace rose to a height of from 300 to 335 feet. The foundations were carried down to the level of the river Euphrates, and much of the wall was constructed of burned bricks 13 inches by 13 inches by 3 inches thick, laid in bitumen. The inner and outer walls were each 24 feet thick and 36 feet apart, thus making a total of 84 feet. The construction was undoubtedly carried out by military officers, who later became known as military engineers. The cross



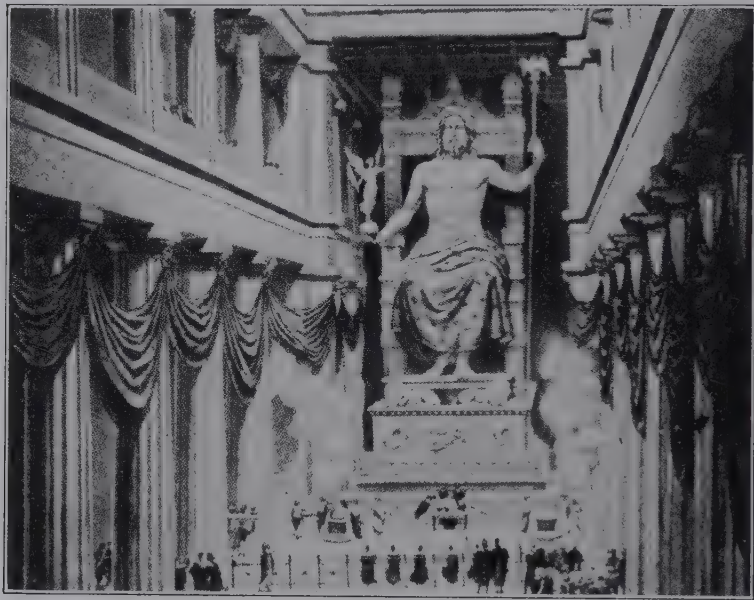
Great Wall of Babylon

section of the palace walls shows a series of six parallel walls, and they as well as the City walls were strong enough to resist all military assaulting engines of the time.

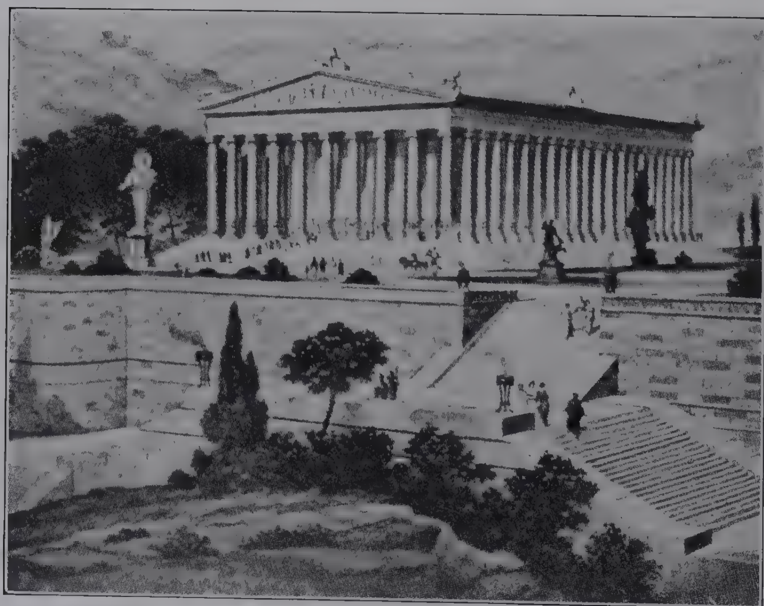
The great Temple of Zeus at Olympia was built by the Greeks just subsequent to 470 B. C. It stood upon a substructure three steps high, and the interior was 142 feet 6 inches wide by 327 feet 7 inches long. It was peripteral hexastyle in plan with 13 columns on each side nearly twice as high as those of the Parthenon, and the total height of the building was 120 feet 5 inches. Just as it was being completed along came the Sculptor Phidias who had fled from

Scottish Rite Temple at Washington

Athens, and he was commissioned to decorate the interior of the Temple with a great image of the God Zeus. The statue was overlaid with plates of ivory, and much gold, silver, and precious stones were used. The base was 20 by 30 feet and the top of the statue reached the roof. Phidias the sculptor evidently combined in his person much of the architect and much of the engineer, to construct also the base and the framework of the great figure.



Statue of Zeus



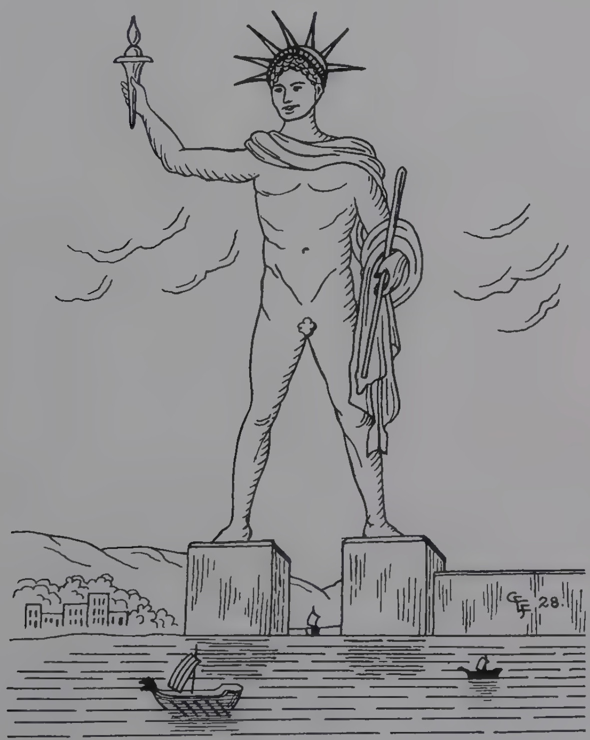
Temple of Diana at Ephesus

The great Temple of Diana or Artemis Brauronia was 164 feet wide and 342 feet long, but the foundation covered an area of 239 feet wide by 418 feet long, and presented one of the first difficult foundations to be recorded. The historian Pliny describes this spread foundation for which "a marshy soil was selected for its site, in order that it might not suffer from earthquakes, or the chasms which they produce. On the other hand, again, that the foundations of so vast a pile might not have to rest upon a loose and shifting bed, layers of trodden charcoal were placed beneath, with fleeces covered with wool upon the top of them." Not a bad solution for the engineer superintendent of the Architect Chersiphron. The 127 columns are 60 feet in height, and each one was presented by a different King. Pliny describes another engineering feat which was performed in placing the lintels and architraves. "The great marvel of this building is, how such ponderous architraves could possibly have been raised to so great a height. This, however, was effected by means of bags filled with sand, which were piled up upon an inclined plane until they reached above the capitals of the columns; then as the lower bags were gradually emptied, the architraves insensibly settled in the places assigned them. But the greatest difficulty of all was found in laying the lintel placed over the doors. It was an enormous mass of stone, and by no possibility could it be brought to lie upon the jambs which formed its bed; in consequence of which, the architect was driven to such a state of anxiety and desperation as to commit suicide. Wearied and quite worn out with such thoughts as these, during the night, they say, he beheld in a dream the goddess in honour of whom the Temple was being erected; who exhorted him to live on, for that she herself had placed the stone in its proper position. And such, in fact, next morning, was found to be the case, the stone apparently having come to the proper level by dint of its own weight." The Christian Era brought about the desertion of the worship of Diana, and the Temple fell to ruins, so that when the stones had been carried away to construct other buildings, the river overflowed the banks and the site of the Temple again became a swamp, where the modern engineer would hesitate to build any foundation.

The Tomb of Mausolus, or as it is usually called the Mausoleum at Halicarnassus, is well known from the Scottish Rite

Thomas Telford

Temple at Washington, which was built to resemble it, by the famous architect John Russell Pope. The King Mausolus who was the son of Hecatomnus, married his sister Artemisia, and they both were said to be endowed with remarkable beauty and wisdom. When Mausolus died, Artemisia is said to have had the body cremated and to have mixed the ashes



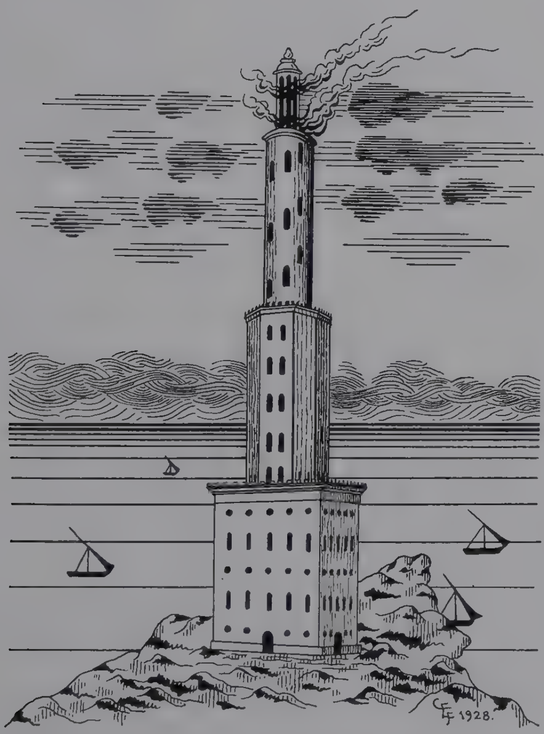
COLOSSUS OF RHODES

with the wine she drank. However that may have been, she built the tomb which was the first of the kind which we now term Mausoleums, although it was not fully completed until after her death. The base was 86 by 119 feet and the height to the top of the horses and chariot was 142 feet. The horses and chariot which were 13 feet 3½ inches high, are now in the British Museum, together with portions of the frieze, the statues of Mausolus and Artemisia, and other details. The architects were Satyros and Pythias, and Scopas was the mas-

PERSIAN STONE BRIDGE AT DIZFUL

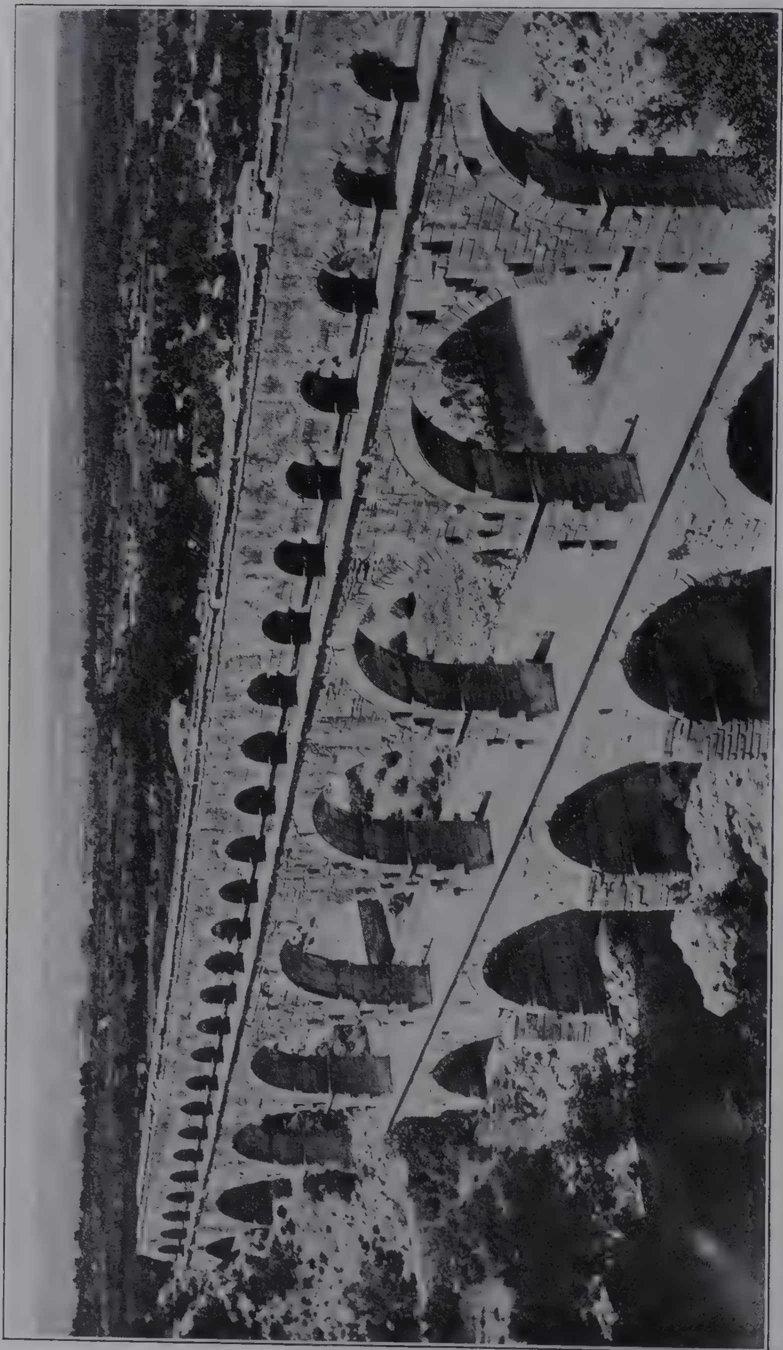
CHINESE STONE ARCH

ter sculptor. The engineering work was notable, as the rock was excavated to a depth of fifteen feet, and the foundation measured about 108 by 127 feet. The green stone was quarried nearby, and the blocks four feet square and one foot thick, were fastened together with iron clamps.



Pharos at Alexandria

The Colossus of Rhodes was in reality a work of harbor engineering, built about 280 B. C. and is supposed to have served as a light to ships coming into the harbor of Rhodes. It was a great figure of a man of a height of 105 feet, and on piers about 40 feet in height, astride the entrance to the harbor. The sculptor-engineer Chares built the figure of brass, with the interior filled with rocks to give it stability. Pliny writes an account of this sixth wonder of the world. "Most worthy of admiration is the colossal statue of the sun which stood formerly at Rhodes, and was the work of Chares the Lindian, no less than seventy cubits in height. The



Pont du Gard Nimes France

statue, fifty-six years after it was erected, was thrown down by an earthquake, but even as it lies, it excites our wonder and imagination. Few men can clasp the thumb in their arms, and the fingers are larger than most statues. Where the limbs are broken asunder, vast caverns are seen yawning in the interior. Within, too, are to be seen large masses of rocks, by the aid of which the artist steadied it while erecting it."

The seventh wonder of the ancient world was the Pharos of Alexandria, the prototype of our modern lighthouses, and was truly a work of harbor engineering. It was begun about 285 B. C. by Ptolemy Soter and was finished about 247 B. C. by his son the Ptolemy Philadelphus. Pliny writes of this great work, "There is another building, too, that is highly celebrated, the tower that was built by the king of Egypt on the island of Pharos at the entrance of the harbour of Alexandria. The cost of its erection was eight hundred talents, they say; and not to omit the magnanimity that was shown by King Ptolemaeus on this occasion, he gave permission to the architect, Sostratus of Cnidus, to inscribe his name upon the edifice itself. The object of it is, by the light of its fires at night, to give warning to ships, of the neighboring shoals, and to point out to them the entrance to the harbour. At the present day there are similar fires lighted up in numerous places, Ostia and Ravenna for example. The only danger is that when these fires are kept burning without intermission, they may be mistaken for stars, the flames having very much that appearance at a distance." The most likely restoration of it makes the height about 600 feet, with the first stage of 180 feet a square, on top of which was a terrace. The next stage was octagonal with a terrace at the top, while the third stage was circular, and the fourth of tall bronze columns, within which burned the fire to light the ships at night, and guide them by the smoke during the day. The traditions of the Arabs tell of an interior shaft reaching to the top, with a spiral stairway for the climbers. There were also chambers in the lower portion, and tradition places the number at three hundred. There was also a mirror at the top, which may have been a lens, as it was said to disclose ships farther than the human eye could see them. Finally the Pharos disappeared; step by step the earthquakes shook it down, until by

Old Roman Aqueduct

Bridge of Augustus at Rimini

about 1500 A. D. it had all vanished. Now a modern lighthouse occupies the site, and of all these seven wonders of the ancient world only the Pyramids remain.

The record of other ancient engineering works might be multiplied indefinitely, as the city planning, the water systems, the harbors, the roads, the bridges, and all else that made for civilization, were carefully carried out and constructed by the architects and engineers of the past. The voussoir arch dates back further than the well known Babylonian one of mud bricks, built sometime about 4000 B. C. The arch bridges of China and Persia are many of them hoary with age, those of China being circular, and those of Persia are pointed or gothic. The old stone bridges of the Roman Empire are best known, as many of them are still in existence. The bridge of Augustus at Rimini consists of five semi-circular arches, three of 28 feet 9 inches span, and the two shore spans of 23 feet 5 inches span. The piers are very thick and carry as decorations two columns supporting an entablature, thus indicating that the designer of that day made mistaken applications of architectural detail, which error has persisted to the present.

The Pont du Gard at Nimes, France, is another one built by Augustus, the upper stories being an aqueduct which has been long in disuse, and the lower story, carrying a road, which is still carrying traffic. Hamlin in his "History of Architecture," says "these Roman works of utility were in many cases designed with an artistic sense of proportion and form which raises them into the domain of genuine art. A remarkable effect of grandeur was often produced by the form and proportions of the arches and piers, and an appropriate use of rough and dressed masonry. They are impressive rather by their length, scale, and simplicity, than by any special refinements of design."

The structure illustrated was a part of a great aqueduct system. It has a height of 161 feet from the bed of the river, a length at the top of the first story of 562 feet, and at the top of the second story of 885 feet. The large arch, through which the river Gardon runs, is 80 feet 5 inches, the other large arches from 51 to 63 feet span, while the small arches of the upper story are 15 feet 9 inches. The original width at the top of the first story was 20 feet 9 inches, while the

second is 15 feet, and the third 11 feet 9 inches. There is now room on the first story to allow for travel across the valley.

The foundations are built on bed rock, six feet above the stream, the entire structure being built of a fine-grained freestone, quarried near the site; the blocks are many of them very large, only two or three for the width of each pier, the piers having triangular cutwaters and laid in courses of about two feet. The projecting stones or corbels seen on various

ROMAN MOLE AND LIGHT POZZUOLI

parts of the structure were used to support the centering on which the arches were built. The keystone for the large arch is 5 feet 3 inches, for the other large span 5 feet, and for the small ones 2 feet 7 inches. The arch stones are not bonded crosswise, there being several distinct arches in the thickness.

The cut stonework is laid without cement, depending on nice fit and weight for solidity, each stone having been lowered into place by the lewis; rubble work was used for the filling in of the piers, spandrels and haunches of the first and second stories and for the work above the third story which formed the water conduit, and which was laid in cement, now as hard as the rock itself. The channel was 4 feet in width by 4 feet 9 inches in height, being lined with 2 inches of

cement, and this in turn covered with fine dark red mastic, giving a surface as smooth as polished marble; the channel being covered with stone slabs.

The arches are all semi-circular and very simple as was the Roman custom, but the effect is magnificent and the structure worthy of much study. There are no more striking examples of the grandeur of simplicity in the design of stone bridges than the old Roman aqueducts. The long lines of arches still standing on the otherwise deserted plains of the Campagna, are examples likewise of the splendid character of the workmanship of the Romans, who apparently built their engineering structures to last for all time. The rectangular stone piers were capped with simple stone copings, the full semi-circular arches sprang directly from these, while the depth above the arch ring necessitated for the conduits, ornamented by simple belt courses and surmounted by a coping and a triangular capping, gave the structure a dignity which even in the ruined condition of the present time has not been lost. The engineering skill displayed in their design was remarkable, showing that the Romans were well informed in scientific matters. The conduits have uniform grades for long distances, having been apparently constructed from precise levels of the country over which they were built.

The stone of which they were constructed was carefully squared, and in some instances different colored stone was employed for architectural effect. Most of the work was done upon them during the winter season, as the masonry was thought to dry out too quickly if laid in the summer. There were nine aqueducts used to supply the city of Rome with water in the time of Frontinus, the Aqua Appia, Anio Vetus, Aqua Marcia, Aqua Tepula, Aqua Julia, Aqua Virgo, Aqua Alsietina, Aqua Claudia, and the Anio Novus. Of these the Aqua Claudia was the most remarkable for its construction and arrangement, having a length of nearly fifty miles and carrying water from two streams above Tivoli. Nearly one-third of its length was carried on arches.

The harbors of the ancients were well suited to the ships of the time, and were protected by sea walls or breakwaters, with some very elaborate piers or landing moles. The picture of one found among the ruins at Pompeii had seven arches to allow the current from the sea to pass freely, while

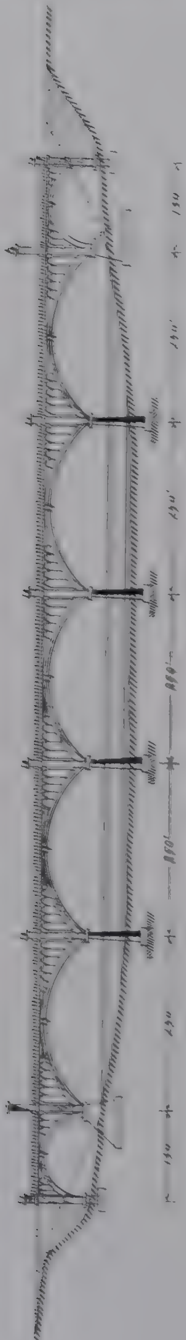
on the deck were triumphal arches or trophies. The mole at Pozzuoli had fifteen arches, and at the end was the pharos or lighthouse. The Port of Ostia constructed by Claudius was one of the boldest constructed by the Romans. It was an oval basis protected by moles, and there was a pharos of classic design of five stories, with a colossal statue of the Emperor. The harbor of Ancona was one of the principal naval stations of the Romans, and the mole constructed by the Emperor Trajan still remains.

The Bridge of the Rialto at Venice built by Michelangelo in 1578, well illustrates the bond which should exist between the artist, the architect, and the engineer. The bridge is a single arch of 96 feet 10 inches span, on the two sides of which are rows of shops formed by arcades of marble, and footways are supported on each side by corbels and protected by balusters. Thus with the center space there are three aisles reached at the ends by marble steps. The design exhibits the touch of the artist and architect, while the construction bespeaks the engineer. The arts of painting, sculpture, and architecture have now become so specialized that seldom are any of the two practiced by one person, and more seldom is the skill of the engineer combined with any one of these arts. The architect must have enough knowledge of engineering to enable him to construct the skeleton of the building he is to decorate, and the engineer must learn enough of art to avoid making the hideous mistakes of engineering design which dot America from coast to coast, and from which no country is free. The modern architect must needs have on his staff engineers to design the foundations and the structural portions of his buildings, but the average engineering works, usually have so little need for any decorations, that they have been allowed to go without either decoration or artistic design. The day of the engineer as developed from an axeman or a rodman has passed, and now each engineer must be technically trained at a scientific school. Just as the schools of architecture include in the curriculum the needed engineering training, so must the engineering curriculum include requisite artistic studies and the developing of engineering architecture. The fundamentals of such artistic training are simple, and with these mastered, the engineer must enlarge upon them as his greater engineering knowledge develops in practice.

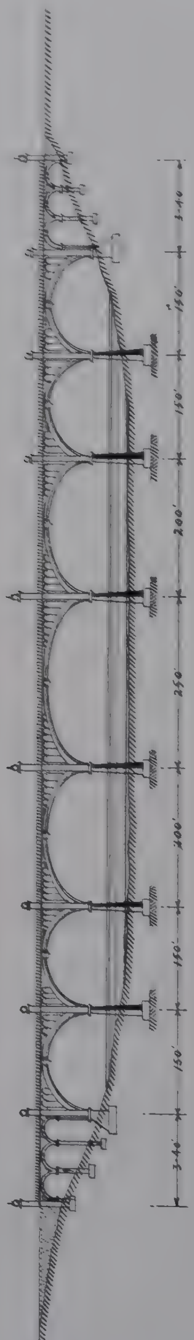
CHAPTER II.

FUNDAMENTALS OF AESTHETIC ENGINEERING DESIGN.

The engineer has become accustomed to regard the mathematical curves with which he has to do, to be so inherently beautiful, that nothing further is required for the structure which incorporates one or more of them. The circular curve, the parabola, the ellipse, the hyperbola, the cycloid, the spiral, and the catenary, are the most common of these graceful lines, but the first three are the most common and the most useful in engineering design. The circular curves are the easiest to use and are very common in arch bridges, tunnel portals, and all sorts of engineering plans or designs. The ellipse, or the three or five centered ovals which are often substituted for it, are also very often used for the curve of an arch; while the parabola is the curve of the suspension bridge cable, when the load modifies the catenary curve of the unloaded cable. The structure employing any of the curves in its design may be said to have the basic element of beauty, but there must be added artistic elements of other and various kinds to make a structure truly artistic, beautiful or pleasing. The flat arch bridge or one of small rise, of one span, may best be designed by using an arc of a circle, or by giving the intrados an elliptical outline. The arch of greater rise may have a half circle for its outline, or an elliptical form may be employed. The arch bridge of several openings must have an odd number of spans if it is to be truly artistic and pleasing, as a pier at the center is an unpleasing feature. Therefore it is desirable to fix the number of spans at three, five, or seven, as beyond seven the eye of the observer does not so readily detect the violation of this basic principle. Where there is an approach of considerable length at each end of a bridge, each one may consist of three shorter arches, flanking one, three, five, or seven main spans, and such a combina-



Concrete Arch Bridge Design C. E. F.



Concrete Arch Bridge Design C. E. F.

tion of nine, eleven, or thirteen spans would be found very pleasing and satisfying to the observer. Likewise the spandrel arches carrying the roadway in each main span, should be three, five or seven in number each side of the center. When it is necessary to carry the spandrel or supporting arches across the center of a span, an unequal number may be used. The long bridge, viaduct, or other structure to be designed, such as the face of a dam, may well have the arches, openings, or decorations in groups of three, five, or perhaps of seven.

The above basic principles must be harmonized of course with the best location for a bridge structure, the amount of clear waterway required, the form of the arches or spans, the length of the arches or spans, the foundations possible, and the width of the structure. Sometimes the location of the bridge is fixed, and all features of its design must be to some extent subordinated to this necessity.

The four fundamentals to a complete and satisfactory bridge or some other engineering structural design, are Simplicity, Symmetry, Harmony, and Proportion, and these must be regarded in any design that would have any pretentions to beauty or artistic effect. While their mere observance may or may not produce a wholly artistic and satisfying design, they must be applied as the basic principles of any structure when artistic thought is given to the plan.

Simplicity means primarily a truth telling structure, having no subterfuges about the lines of stress, no covering of concrete or steel with a stone facing, no frivolous or inappropriate details, but a strict adherence to the necessary features for stresses or appearance, whether to carry the loads or merely to ornament the structure.

Symmetry may or may not be absolutely essential to a pleasing and satisfying design, although it is usually necessary if a truly artistic structure is to result. When the structure is of great length, unsymmetrical features are not so noticeable as in a shorter one, which can all be seen at a glance. Sometimes balance must be secured by including in the design an unsymmetrical feature, such as an artist often finds to be necessary in a landscape composition. The case may be one where a draw span or other unbalanced feature

Conway Bridges and Castle

must be included in the design, and which will destroy its symmetry, so that something must be added to restore the balance, although absolute symmetry does not result. Symmetry in its simplest form is where one half of a structure is exactly a duplicate of the other half, and the approach at one end is a duplicate of the approach at the other end. Then the structure is perfectly balanced in the simplest manner. The most pleasing design is reached when the center of a bridge is at the center of the middle or main span.

Harmony is also essential to a pleasing or artistic design, because without it the structure would most surely be displeasing to the beholder. There must be harmony between the substructure and the superstructure; between the various component parts of the design; between the utilitarian features and the ornamental details; and complete harmony with the surroundings and the structures in the vicinity.

Harmony is best exhibited where no parts of a structure or of its decorations seem to be extraneous, and where the structure harmonizes with its surroundings. This latter feature is illustrated by the harmony of the battlemented towers of the Conway suspension bridge and the Conway tubular bridge, with Conway castle; by the harmony of the medieval towers of the London Tower Bridge with the Tower of London; and by the harmony of the stone towers of the old Brooklyn bridge with the high buildings of New York City, although this is but a happy accident, as the buildings were the later development.

Proportion is closely related to each of the three foregoing principles of design, and usually but not always, when the economic proportions have been determined the resulting designs are pleasing and artistic. However in most cases, modifications may be made so that the requirements of both economy and beauty can be satisfied. The proportion of the details employed for ornamentation is a distinct feature of a design, and to be harmonious they must be of the correct type, properly applied, and rightly proportioned. Proportion is most nearly reached when the entire structure is most pleasing to the trained eye, and the truth most closely adhered to in every part of the structure, and in every detail. The use

Tower Bridge and Tower of London

of too great a sag in a suspension bridge, or of too great a rise in an arch, often dwarfs the apparent length of such a span, and the sag or rise is too great for appearance, even if not too much for economy.

The final design of any engineering structure should only result after a most careful study of an outline elevation, with enough of the details sketched in, to make sure of the bearing of each item on the ensemble. Such a drawing should be pinned up where it can be constantly seen, and change after change made of lines and details which are not pleasing or which appear to violate the spirit of the work. The criticisms of other designers should be asked for and heeded, as the design which is intimate to its author, may be too much so for proper impressions. The most successful designer of artistic structures must have enough imagination to see it in perspective, and sense the relationship of one part to the other.

The designing of stone bridges, concrete bridges, and steel bridges must all be governed by the foregoing principles, yet what is appropriate and harmonious for one type, may not be wholly satisfactory for another type of structure, and these differences will be discussed in the chapters devoted to their detailed design. There have been comparatively few dams designed with any particular reference to artistic treatment, but such of them as have been so treated, can well come under the foregoing principles and it is to be hoped that hereafter much thought will be given to the embellishment of both gravity and multiple arch dams, along truly artistic and monumental lines.

The towers for the controlling apparatus at dams, and the water towers for cities may well be designed under the general principles of simplicity, symmetry, harmony, and proportion as have been set forth, but with the reservation that they need not be so truth telling as to be unsightly. Power houses and other buildings which come strictly within the province of the engineer, should also be designed with full regard to simplicity, harmony, and proportion. They must often be considered as more nearly monumental works, which must be in full harmony with the mountain masses among which they are placed, just as the pyramids are in harmony with the vastness of the deserts which surround them.

Sir John Fowler

The amount and kind of ornamentation to be placed upon any sort of engineering structure, is perhaps as important as the determination of the form of the structure itself. No matter how carefully a design may be conceived and worked out in its fundamental features, no matter how pleasing may be the outline and ensemble, all may be ruined by the lack or type of ornament used, or the overdoing of ornamentation. Then again a most pleasing outline may be ruined by the use of unsightly details which are an integral part of the design, and which in our present state of knowledge can be replaced by something pleasing, yet answering all the needs of the stress diagrams or practical purposes of the structure, while being as much or more economical. The decoration of the old Roman bridge of Augustus at Rimini with classic columns supporting an entablature, an entirely inappropriate detailing, has already been mentioned, and this idea was mistakenly copied in the design of the Waterloo bridge at London, although this design was much superior to the Roman one.

The features of inappropriate engineering details have been quite thoroughly discussed by Fergusson in his History of Architecture. "In all these cases," he says, "the primary object of the engineer is use, not beauty; but he cannot help occasionally becoming an architect, and sometimes with singular success, though too frequently, when he ornaments, it is, as architects generally do, by borrowing features from the Classical or Mediaeval styles, or by some mistaken application of them, betraying how little he has really studied the problem before him.

"In illustration of these definitions, let us take the Dee bridge at Chester. As an engineering work, nothing can be nobler. It is the largest single span for a stone bridge in England, probably (at the time) in the world; built of the best materials, and in a situation where nothing interferes with its beauty or proportions. Its engineer, however, aspired to be architect; and the consequence is, that instead of giving value to an arch of 200 feet span, no one can, by mere inspection, believe that it is more than half that width. In the first place, he introduced a common architrave moulding round the arch, such as is usually employed in domestic architecture, and which it requires immense thought to exaggerate beyond the dimensions of a porte-cochere. He then

Chester Dee Bridge, Derby, England

placed in the spandrels a panel 30 feet by 50, which, in like manner, we are accustomed to, of one-third or one-thirtieth these dimensions. He then, on his abutments, introduced two niches for statues, which it is immediately assumed would be of life size; and beyond this, two land-arches without mouldings or accentuations of any sort, consequently looking so weak as to satisfy the mind that there was no difficulty in the construction.

"Had Mr. Harrison been really an architect, he would have rusticated these land-arches with Cyclopean massiveness, not only to continue the idea of the embankment, but also to give strength where it was apparently most needed; and would have avoided anything in the abutments that savored of life-size sculpture or of temple building. A mediaeval architect would have pierced the spandrels with openings, thereby giving both lightness and dimensions to this part; or, if that was not mechanically admissible, he would have divided it into three or four panels, in accordance with the construction. The essential parts in the construction of a bridge, however, are the voussoirs of the arch; and to this the architect's whole attention should first be turned. If there had been fifty well-defined arch stones, the bridge would have looked infinitely larger than it now appears. With one hundred it would have looked larger still, but, if too numerous, there is a danger of the structure losing that megalithic character which is almost as essential as actual dimensions for greatness of effect. The true architect is the man who can weigh these various conditions one against the other, and strike a judicious balance between the different elements at his command. At Chester the builder has failed in this at every point, and by the same process which ruined St. Peter's. By exaggerating his details, the bridge has been dwarfed in exactly the same manner as the basilica.

"If this is all that can be done with bridges, it is far better that they should be left, like most of those recently built, to tell their own tale without any ornament whatever. A long series of tall arches is so beautiful an object in itself that it is difficult to injure it; but occasionally a slight moulding at the impost, a bold accentuation of the arch, and bold marking of the roadway render those beautiful which otherwise may only be useful in appearance."

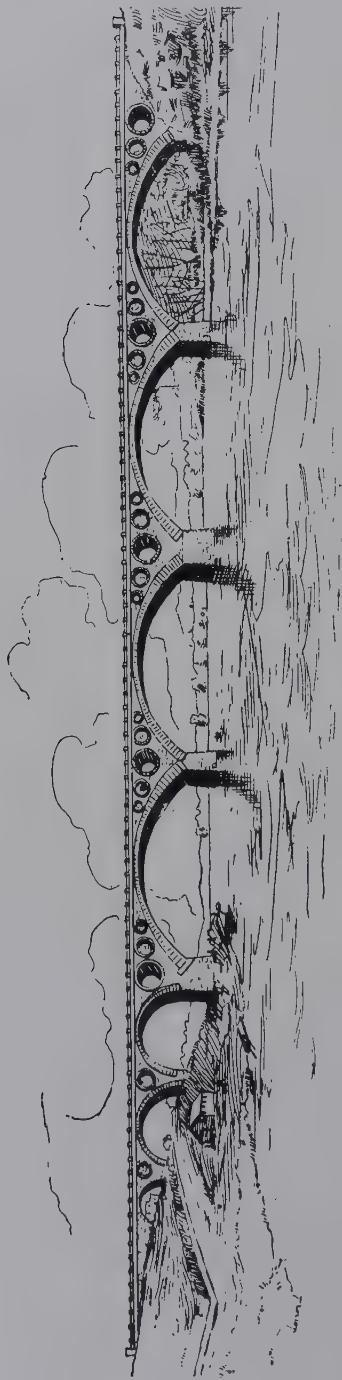
The Washington Bridge over the Harlem

The architectural classification of the essential features of building design are somewhat different from the foregoing, but are in reality covered by the four basic principles already enunciated. The four principles governing purely architectural design have been stated by some authorities as Sincerity, Propriety, Style, and Scale.

Sincerity is more or less a matter of course in an engineering design, as the purpose of such a structure is nearly always evident, and is covered by certain phases of all four of our engineering postulates. There is much more to fear from carrying sincerity too far in the design of an engineering work, than of lack in observing its essentials. Many engineers, feeling that the mere design for carrying the loads, providing for the stresses, or the taking care of the utilitarian features is the only thing requisite, stop short of the necessary artistic arrangement of the component parts of a structure, and the use of some simple but appropriate decorations, to make their design truly artistic and a work of engineering architecture. Some engineers really profess to see beauty, or at least majesty, in straight lines and unpleasing angles; while others go so far as to produce a so called architectural treatment, which in reality only serves to accentuate unpleasing features. Therefore sincerity is often a fault, and something to be considered most carefully, so that it may not become the ruination of a design.

Propriety is also to some extent covered by our four basic principles, but mainly under the heads of Symmetry and Harmony. To be a proper design a piece of engineering architecture must have symmetry or balance, and harmony among its component parts and with its surroundings. Propriety also demands a truth telling structure, and details which do not appear extraneous.

Style as it is understood in Architecture, is something that can seldom be considered in an engineering design, except in so far as an arch bridge might be considered Romanesque, or in other cases as somewhat Gothic, like the Roebling Brooklyn bridge towers. The Tower Bridge in London as stated, very appropriately had towers of mediaeval design to harmonize with the old Tower of London in the vicinity. With future developments of engineering architecture it may be possible



Knoxville Stone Bridge Design

Knoxville Arched Cantilever

that some day styles may be formulated and classified, but they should never have the same names as the purely architectural ones, nor be confused with them.

Scale is largely a feature of our principle of Proportion, and to some extent it is related to Symmetry and Harmony. The scale of the component parts of an engineering structure is nearly always determined by the economic proportions, or the determination of the utilitarian features, but as has been mentioned, the proportions should not be fixed at such extremes, which in many cases might produce an unpleasing result. Then the details should not be such as would destroy the scale of the structure, as Fergusson has pointed out in the case of the Grosvenor Dee bridge.

The design of a group of engineering structures must be carried out with a unity of purpose in the general design, and application of detail or ornament, so that the ensemble may be pleasing. We now often see some structures of a group with no purpose expressed in their design except utilitarianism, others with a Romanesque motif, and still others decorated with some classic columns and details, thus producing an architectural hodge podge, which perhaps might better have been avoided by using no features in any of the structures except the purely utilitarian ones.

The material of which an engineering work is to be constructed is very largely a governing factor in its artistic treatment, and what might be a very appropriate design for one kind of material, would be very inappropriate for some other material. The need to use granite or other stone, immediately calls to mind the pyramids, the Romanesque type of structure, or perhaps the Washington Monument. The need to use reinforced concrete at once suggests the use of a much lighter or more graceful type of construction, and the need to use steel at once brings up the image of the graceful Eiffel Tower or the web like beauty of a suspension bridge. The great dam of masonry is in as appropriate a setting in a mountain gorge, as are the pyramids in the vastness of the desert. The Washington Monument is appropriately placed in a National Capital with its scores of monuments and monumental buildings, while the Eiffel Tower is appropriately placed in the airy and effervescent Gothic Capital of France, where the Cathedral

of Notre Dame is in its own environment, and in great contrast to the Cathedral of St. John the Divine in America, where it seems to have been transplanted from a native setting, into the company of incongruous cubical apartment houses.

The conception of the design of a work of engineering architecture must be based first on the amount available for its construction; secondly, upon the use to which it is to be put; thirdly, upon the materials which are to be used; and fourthly, upon a visualization of the location or environment. The successful designer must have the imagination to conceive how his structure will look in its three dimensions of length, breadth, and height. The making of an outstanding structural monument has no relation to the servile copies which dot our landscapes, and it is given to but few to excel the best works of the past.

CHAPTER III.

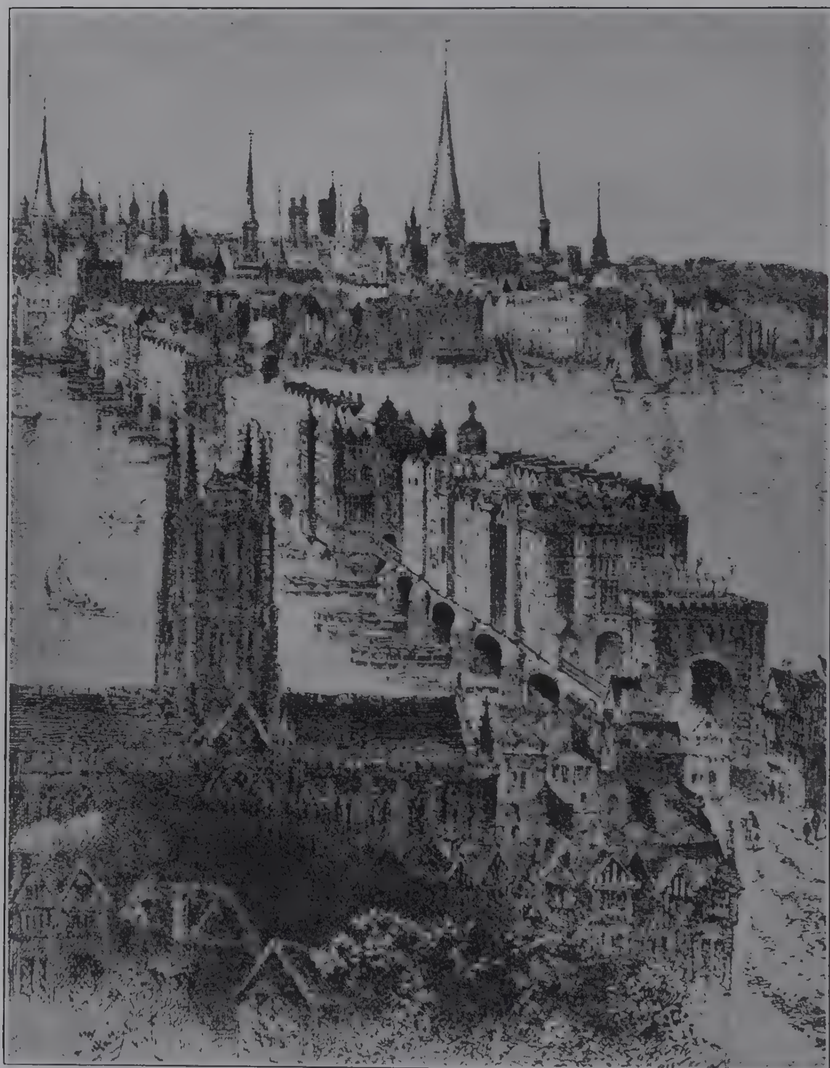
STONE BRIDGE DESIGN.

The designing of stone bridges is based upon centuries of experimental construction of such structures all over Europe and in Oriental countries. The bridge built by William Edwards, a Welsh stonemason, at Taaf near Llantrissart in 1746, may be considered a typical example of such experimentation. The first bridge of three spans was washed out

PONT-Y-PRIDD BRIDGE WALES

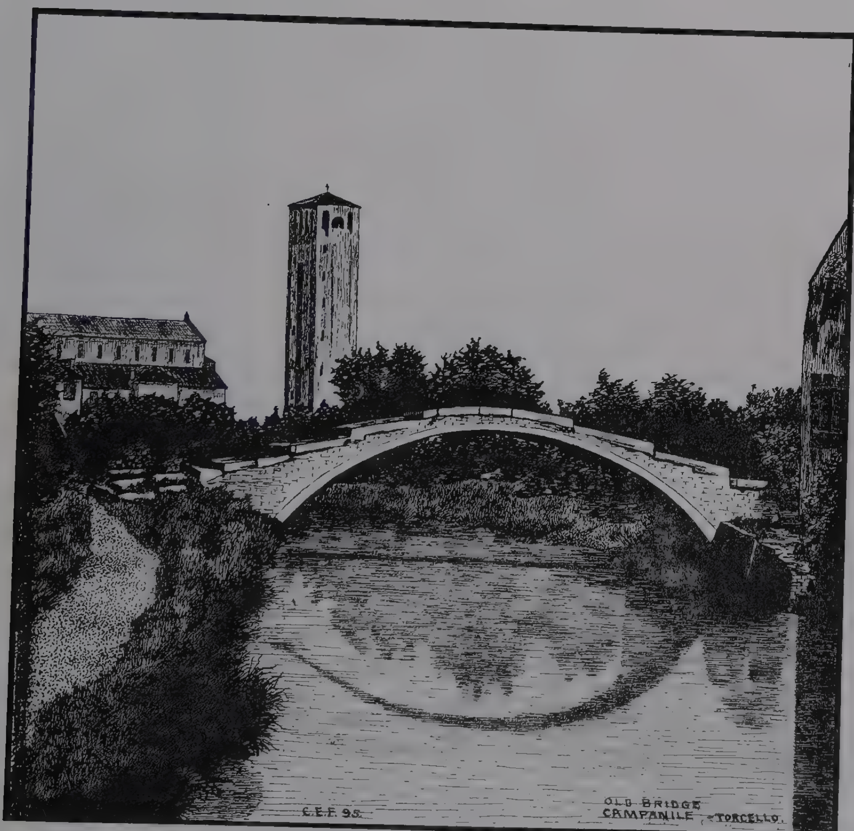
by a freshet, so its failure may be attributed to faulty foundations. Undaunted by this failure, Edwards next tried a single span, which sprung up at the center, due to too much weight upon the haunches. The third one had the haunches lightened by three circular openings in each of the spandrels, extending entirely through from side to side; the first hole being 9 feet in diameter, the second 6, and the third of 3 feet, so that this 140 feet span was a success. The fame of this was widespread, and Edwards was called upon to build many other bridges!

Just how the old Babylonian arches were developed is of



OLD LONDON BRIDGE

course not known, nor is there much to explain the experimental work that preceded the building of the many Chinese, Persian and other Oriental stone arch bridges. The Romans certainly proceeded upon a more scientific basis in the building of the many stone spans all over the Empire. The work of the mediaeval architects or engineers of Europe was based upon the stone bridges of the Romans, which were available



Roman Bridge at Torcello

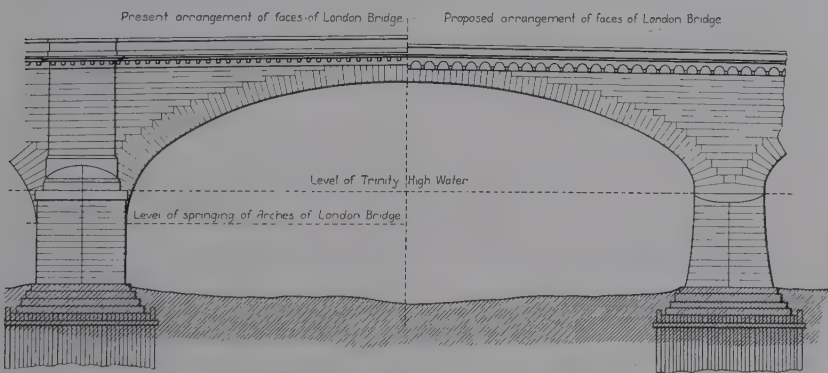
for study and for a probable somewhat servile copying. The early bridges of England were the work of the Brothers of the Bridge, and nearly all subsequent to the Norman conquest.

The first bridge across the river Thames was of timber and was built by Etheldred in 1002. The first stone bridge was built by Peter Colechurch who began it in 1176, and continued

John Rennie

the work during the reigns of Henry II and Richard I, and into the second year of the reign of King John, when he died and was buried in a crypt of a chapel built over the center pier, as was the custom when a Brother died. Another Brother, Isembert, completed it in a few years thereafter. It had a length of 926 feet, a width of only 15 feet, and was 60 feet above the water. The Monnou bridge near Monmouth; the Rochester bridge built at the expense of Sir Robert Knolles; the Croyland triangular bridge; the Ouse bridge at York; and the Laythrope bridge all belong to the same period.

The latter part of the seventeenth century saw the building of a great many notable stone bridges in Europe, and the



London Bridge Alternate Designs

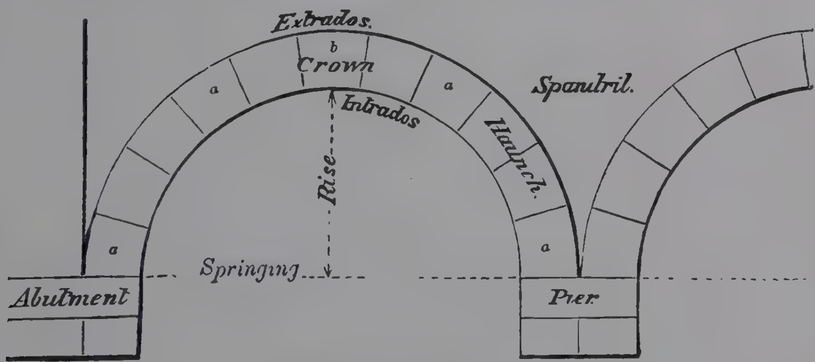
beginning of real care and taste in their design. Among these may be mentioned the Westminster bridge of thirteen semi-circular spans, begun in 1738; the Blackfriars bridge of nine elliptical arches, begun in 1760; one over the Tay, of seven arches in 1763; the Coldstream bridge of five spans in 1763; the Kelso bridge of five spans in 1799, which became the model for the Waterloo bridge of nine spans which was begun in 1811; and the London Bridge of five elliptical arches, which is one of the most famous in the world, being started in 1824 and completed in 1831. The bridge at Trilport over the Maine in France, finished in 1760 had three tasteful elliptical arches; the bridge of Saumur had twelve elliptical arches, and was finished in 1764; the bridge of Neuilly over the Seine had five elliptical arches, built by the famous Perronet in 1774; the bridge of Sevres consisted of nine main spans of semi-circular

New London Bridge

Waterloo Bridge London

arches; while the Pont de Jena, built to commemorate that important victory of Napoleon, had five equal segmental arches of extreme simplicity of design, but very pleasing in detail.

The stone arch lends itself to perfection of design, to a greater extent perhaps than any other type of engineering structure, and while the fundamentals are now largely fixed by theoretical considerations, only the architectural features of design will be discussed in this chapter. The naming of the various kinds and portions of stone arch bridges will be given here, so that the descriptions of various structures may be fully understood. The inside curve of the arch ring is termed the intrados, while the upper curve is termed the extrados.



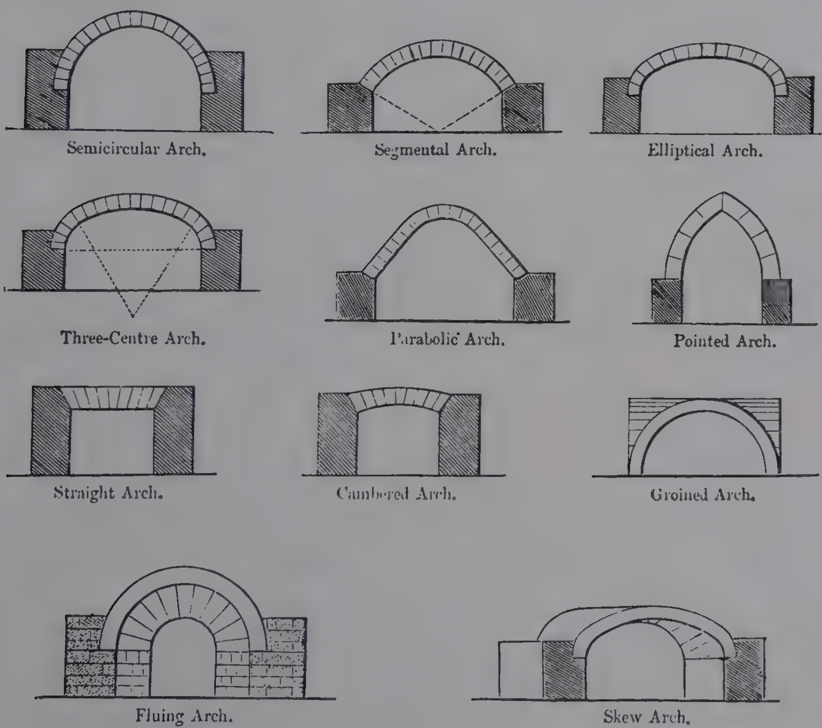
ARCH NOMENCLATURE

The shape of the intrados determines the type of the arch. The semi-circular arch has a semi-circle for the curve of the intrados, while the segmental arch has only an arc of the circle for this curve. The elliptical arch has an ellipse for the curve of the intrados, which is often, for simplicity of construction, approximated by a three, five, or seven centered half oval. Then there is the parabolic arch; the pointed arch; the straight arch; the cambered arch; the groined arch; the fluing arch; and the skew arch, shown in the figures herewith.

The arch ring or the space between the intrados and the extrados is composed of the arch stones, which are termed voussoirs, and the center one the key-stone. The crown of the arch is the top or central portion of the arch ring, while the haunches are the portions at the bottom, or next to the

Pont Neuf over the Seine Paris

pier or abutment. The springing of the arch is the point where the line of the intrados intersects the pier, and the skewback is the stone in the pier or abutment which receives the thrust from the arch ring, while the rise of the arch is the vertical distance from the springing to the crown. The radial joints of the arch stones lie on what are termed the sommering lines. The spandrels or spandrel walls are that



TYPES OF ARCHES

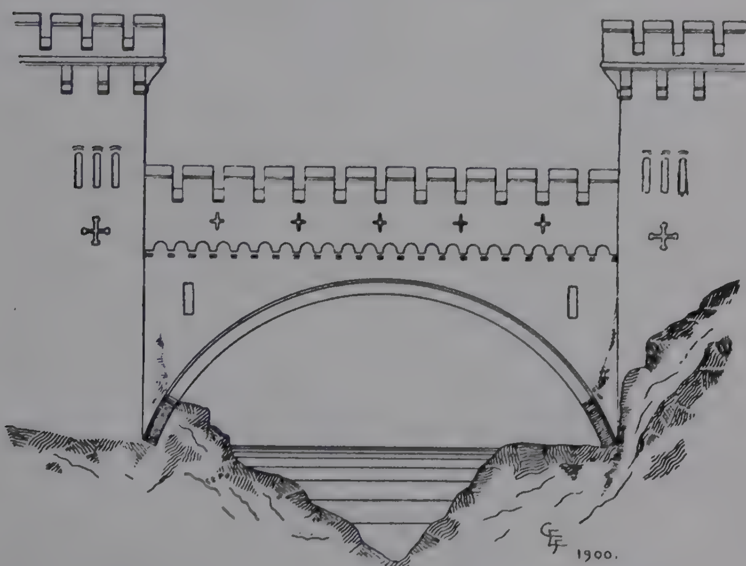
portion of the structure lying between adjoining arch rings, or between an arch ring and abutment. These are all designated on the figure.

The artistic design of a stone arch requires a very careful study and consideration, of the shape and disposition of all the component lines and parts. When the line of the roadway is high and the location of the skewback is low, the semi-circle or a deep ellipse may be used for the curve of the intrados, unless the necessary clearance or waterway requires the use

Bridge of the Trinity, Florence

Pont de la Concorde, Paris

of a segmental arch or very flat ellipse. The use of semi-circular arches is very pleasing for a long viaduct or bridge, where they can be disposed in groups of three or five arches in a section; or very appropriate where they are used in approaches to a long main span. Generally however, it is considered that an elliptical arch is the most pleasing outline to employ. The gothic or pointed, and parabolic arches are now seldom employed in stone bridge design, except in short ap-



ROMAN ARCH OVER THE ADDA

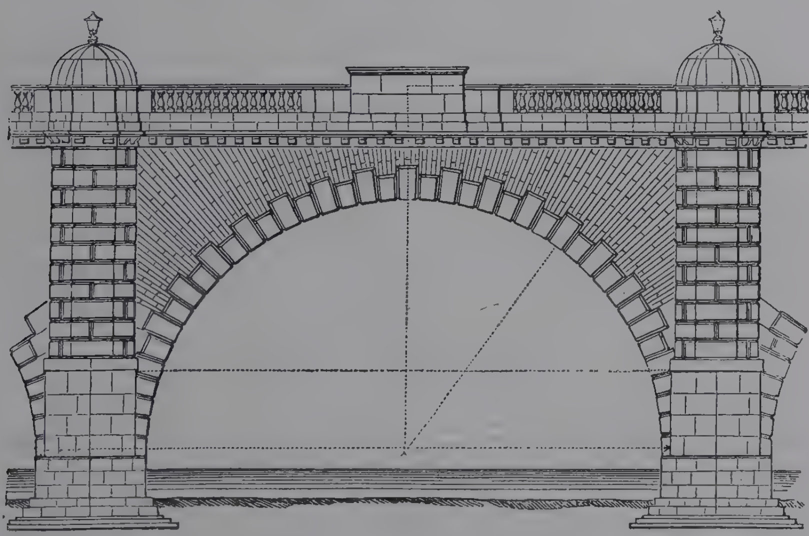
proach spans, or in special cases. The gothic arches in the Persian bridges however, gave great character to the stone bridges of that country.

The curve of the extrados is usually the same as for the intrados, except that for spans of any great length it must be somewhat flatter to comply with theory, and may even be a circular curve when the intrados is made an ellipse, for better appearance, or for a greater area of clearance. The stone or stones comprising the skewback, must be designed to harmonize both with the details of the pier and with those of the arch itself. The arch stones must be designed of the necessary depth to carry the pressures, and of a width to give an

New Bridge of Ayr Scotland

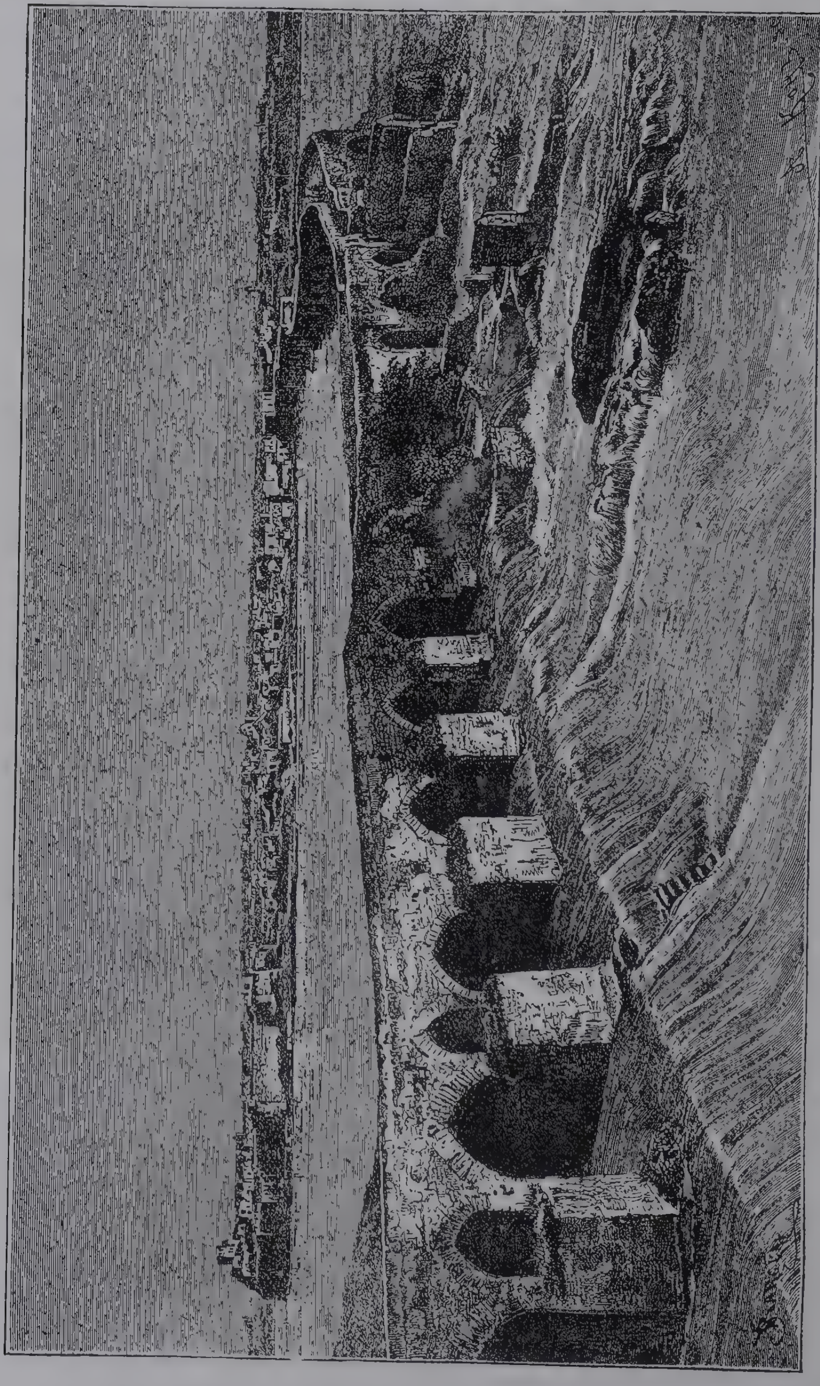
Jeremcze Bridge Austria

appearance of good proportion, which of course cannot exceed what is possible in the stone available. The width should lie between one half and three fourths the height, and not be so small as to unduly increase the cost due to having to lay an excessive number of stones. The joints may be straight and merely pointed with mortar after the arch centers have been struck, or else beveled to accentuate the dividing line, which beveling of course would have to be applied to the top and bottom edges of each stone. The tops of the arch stones may lie exactly on the line of the extrados, or may be joggled



Westminster Bridge London

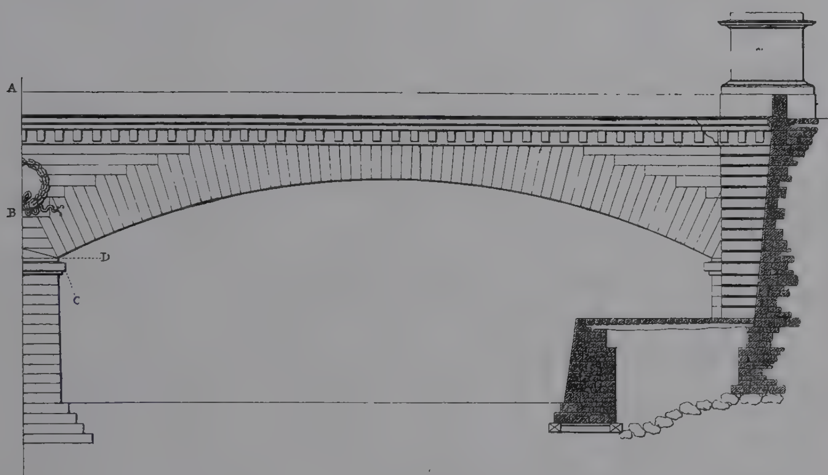
into the masonry of the spandrels, as was done in the London Bridge. The use of a molding along the line of the intrados is objectionable when the arch is of considerable size, but may be found appropriate when the span is quite small. Very often the arch stones are left with a quarry face, and in such cases may or may not have a chisel draft around the edges. When so left, the spandrel masonry is often quarry faced, and also when the arch stones are cut or dressed. The keystone may be especially accentuated, but should seldom be so ornamental as in the Luxembourg bridge, or in the bridge of the Trinity at Florence. The copings and corbel courses surmounting the spandrels, piers and abutments should usually



Persian Bridge over the Karun at Shuster

be of cut stone, very carefully proportioned and detailed, to give a proper cornice effect, and dentils may be used for ornament and for proper corbeling. The design of piers and abutments is discussed in a later chapter.

The application of the foregoing principles may best be illustrated by the description and discussion of some of the notable stone arch bridges of the world. The oldest long



Bridge of Jena Detail

span Roman stone arch bridge of which there is any record is that at Trezzo over the Adda, which is shown in a possible restoration, with the ends of the arch ring which still remain drawn in heavy lines. The span of the arch was 251 feet and the structure undoubtedly was a most imposing one. The bridge of Augustus at Rimini and the Pont du Gard at Nimes, France, have already been referred to as typical of the old Roman stone bridges. The bridge of Augustus is considered an early and typical example of the inappropriate use of classic columns in bridge decoration, and the same mistake was made in the design of the Blackfriars and Waterloo bridges in London. The Pont du Gard should be studied as an example of the building of upper stories of arches upon the bridge proper, although such construction could be done in a more correct and pleasing manner, as was done in the Roquefavour Aqueduct, where three small arches surmounted the

Bridge of Austerlitz Paris

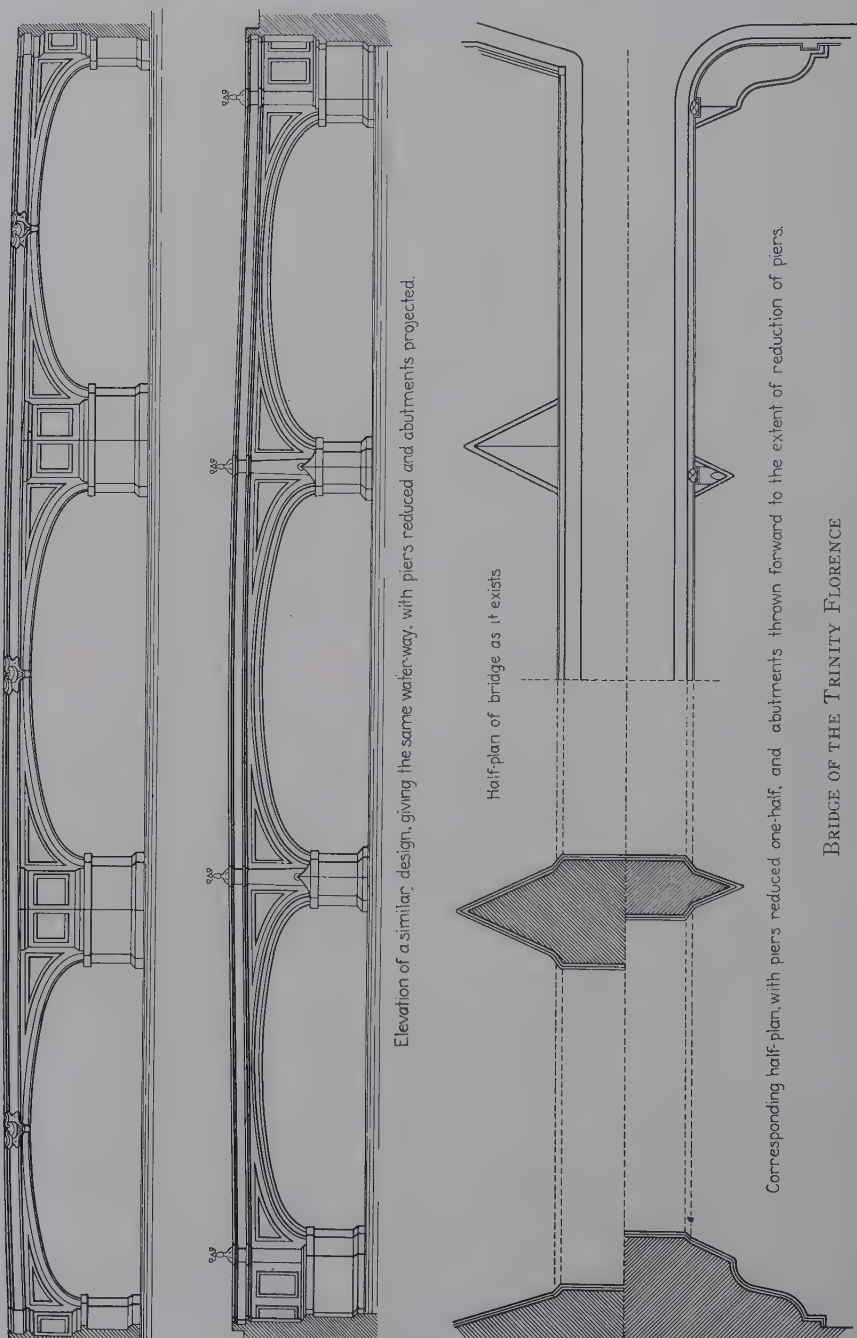
The Great Luxembourg Arch

upper or second tier of the large arches. The stone approaches of the St. Louis Eads Bridge are also quite correctly designed after this manner.

The oldest of the bridges across the Seine in Paris, is the Pont Neuf, begun by Androuet Ducerceau in 1578, and completed during the reign of Henri IV. It however, is a most monumental structure, and quite pleasing, due largely to the overhang or cornice effect, which came about through the widening of the roadway. The Pont de Neuilly, was built by the celebrated Engineer in Chief of the Ponts et Chaussees, Jean Rodolphe Perronet in 1768 to 1774, who will go down in history as one of the world's truly great engineers. There were five elliptical arches of 128 feet span, with a rise of one quarter. The springing of the arches is on a level with low water, and the distance from low water to the neck of the arch is only 7 feet 6 inches. "The arches are brought to a level with the face of the bridge by cornes de vache, terminated by the prolongation of the arc which forms the summit of the ellipse." The small arches in the abutments are very tasteful, while the entire design is very chaste and worthy of study.

Napoleon at St. Helena, in recounting the deeds and works for which he would be remembered, did not fail to mention the bridges he had caused to be constructed, for he was justly proud of the engineering works constructed during his reign. Between the years 1804 and 1813 he expended for bridges alone the sum of 39,305,000 francs, of which sum 3,000,000 francs were for the bridge of Austerlitz, originally built of cast iron, but replaced under Napoleon III with a stone one. This bridge was built to commemorate the greatest of his victories, that of Austerlitz, as others of his bridges were constructed as monuments to other battles where he was victorious. That he did not mistake in choosing his monuments is evidenced by the interest yet taken in the works of his engineers, and from the fact that these bridges are as worthy of study to-day as they were scores of years ago.

The Pont d' Austerlitz is a work of architecture primarily, because of the division of the crossing into five spans, an odd number being the most elementary feature necessary to perfection of design. The arch ring stands out bold and in full



BRIDGE OF THE TRINITY FLORENCE

relief, with the springing of the arches in full view, and not concealed as is the case with many stone bridges, which are otherwise remarkably near perfection. The flatness of the arches is in pleasing contrast with those of more rise, and consequently of greater boldness. The piers on this account become mere supports to the superstructure and are well designed to this end. Above them, decorating the spandrels are the wreath of palm leaves, and the Imperial "N" surmounted by the crown, emblematic of victory and empire, thus fixing beyond question the purpose of the construction. The balustrade is of chaste design, unbroken in detail except over the piers, where a short panel marks the spacing of the spans and serves to break the monotony.

More criticisms have been written concerning the bridge of the Trinity at Florence, Italy, designed in 1750 by Ammanati, than perhaps of any other of equal importance. There are three spans, the center one having a clear length of 95 feet 10 inches and the two side ones 87 feet 7 inches, with a rise of one-sixth the span. The piers, as can be seen from the view which shows one side span, are in reality abutments with the great thickness of 26 feet 3 inches and with prominent acute-angled starlings both up and down stream. The intrados is made up of two parabolic curves, which meet at the center with a slight angle, which is concealed with a large escutcheon that extends up over the parapet as well. The piers are faced with cut stone, the moldings being very elegant. The arch ring is very heavily molded and the spandrels paneled. This method of detailing is not so inappropriate for spans of this length as it is for very large spans and the structure presents a very finished and elegant appearance. Had the two piers been made of only ordinary thickness and abutments employed projecting out from the river walls, the proportions would have been much more pleasing. The parapet walls are of perfectly plain design except a slight molding under the coping, and have pedestals at the ends which are surmounted by statues.

One of the most renowned of modern stone arch bridges is the present London Bridge over the river Thames. It is also one of the most chaste and harmonious designs of the many stone bridges that have been built the world over, and was Rennie's masterpiece. There are five spans of elliptical

outline, the center one having a span of 152 feet, a rise of 37.7 feet, a depth of arch ring at the keystone of 4.8 feet and at the spring of 10.0 feet. The two spans on either side of the center one are 140 feet each, with a depth at the key of 4.6 feet and at spring of 9.0 feet. The two shore spans have a span of 130 feet each, a depth at the key of 4.5 feet and at spring of 8.5 feet.

The piers were founded in cofferdams, one of which was carried 29 feet 6 inches below low water. The stone used was granite, and the masonry, up to the springing of the arches,

[illegible]

was specified to be ashler in horizontal courses of from 15 to 24 inches thickness. All of the arch stones were to be headers, unless the engineer allowed stretchers to be used. At the intrados they were to be 18 inches in thickness and the faces dressed smooth and straight. The spandrels between the arches are of granite and the ring stones of the arch are tailed into the spandrel courses. The cornice and parapets are also of granite, finely dressed and jointed, and none of the stones belonging to the cornice, plinth, dado, or coping, were allowed less than 4 feet 6 inches long. All these stones were to be free from flaws of any description.

The beautiful elliptical outline of the arches is but one

of many details by which an appearance of elegance is obtained. The starlings of almost perfect design are coped and capped in an appropriate manner, and support counterforts, which are very effective in overcoming any tendency toward flatness of design. The parapet or cornice is supported by corbels, and while of the simplest design, is in entire harmony with a most studied and effective piece of bridge architecture.

The "Twa Brigs o' Ayr" have been made famous by the poet Burns, one of the bridges being the old one in the background which is now used only for foot passage, while the new one in the foreground occupies the site of the other, the present bridge being the third to occupy the same place. The bridge consists of five spans of small rise, the side spans being somewhat shorter than the other three. The arch stones are tailed into the spandrel courses in a very pleasing manner and the keystones accentuated by a pyramidal face. The piers have rounded ends, with appropriate coping and caps, and are surmounted by counterforts with molded tops. The dentiled cornice, while very plain, is of neat design, being broken over the piers by the ornamental brackets which support the pedestals of the balustrade.

The parapets or balustrades are of very beautiful design, that over each arch being divided into several sections by paneled pilasters, each section having four circular openings in the dado, with other simple but effective decoration, except that the long spans have an extra panel at the center with only one opening. At the ends and over each pier there are pedestals carrying ornamental lamp posts. The contrast with the old bridge is very great and is a striking illustration of the progress made in bridge design. Scarcely any fault is to be found with the appearance of the new bridge, unless it is the lack of more prominent abutments at both ends, there being an appearance of the bridge having been crowded in between the river walls.

The bridge of Jaremcze in Austria, designed by Ludwig Huss, has a main span 213 feet long, or at the time it was built the second largest stone span in existence. The arch ring has well defined and exposed skewbacks, and is constructed of cut stone. The spandrel arches have a span of 11.8 feet, while the short approach spans are 26.2 feet and the longer ones 39.4 feet. No particular effort seems to have

Cabin John Arch Washington

High Bridge Harlem River

been made for architectural embellishment, entire reliance having been placed on the simplicity and boldness of the design, but it is to be regretted that a coping or cornice was not added to finish the structure.

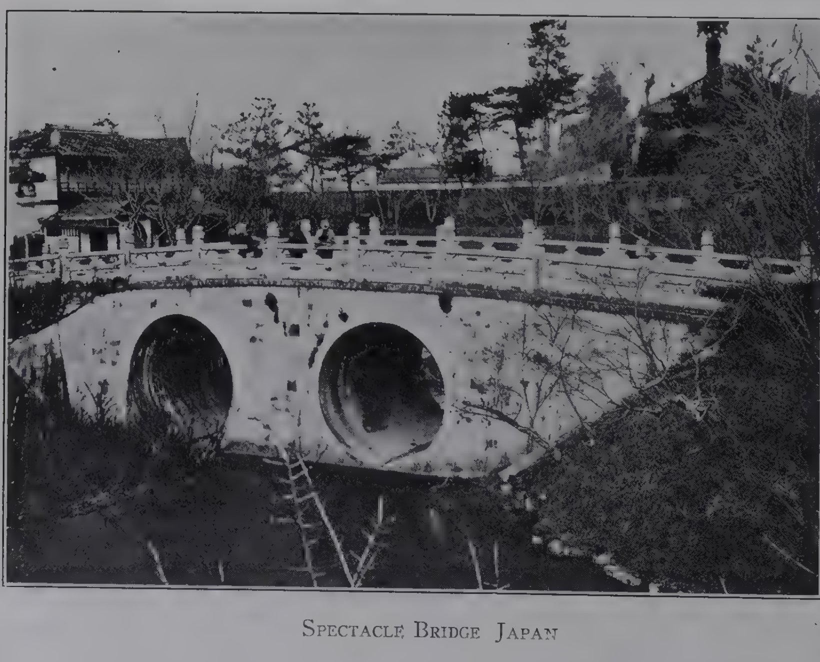
The largest stone arch in existence in the United States at the present time, is the Cabin John bridge and aqueduct over Rock Creek, at Washington, D. C. It was designed by Gen. M. C. Meigs, and has a span of 220 feet, a rise of 57 feet, while the roadway of 20 feet width is 101 feet above the stream. The arch ring is of granite, six feet deep at the crown and four feet at the center; the spandrels are of sandstone, laid partially with radial joints. The splendid architectural effect is due to the proportions, and to the relief afforded by the projecting courses at the roadway, which gives a cornice like effect in entire harmony with the whole design.

The great Luxembourg stone arch bridge of 275 feet span, was for many years the longest stone span in the world, and is now the third longest, being exceeded by the 295 feet span at Plauen, Germany, and the 279 feet span at Trieste, Austria. The rough skewback masonry is of very questionable propriety, and certainly out of harmony with the finely molded cut stone arch ring, the great keystone escutcheon, and the neat spandrel arches. The design is still further marred by a rough stone corbel course. With all the glaring faults it is nevertheless of very imposing ensemble.

High Bridge is the most notable stone bridge in the United States, not on account of the size of the spans, but because of its height, chaste design and monumental character, and carries the Croton Aqueduct over the Harlem River at New York City, from the mainland to Manhattan Island. The erection of the remarkable Washington Bridge, close to it, with its great steel spans, instead of detracting from its appearance as might be expected has only enhanced it. The recent insertion of a long steel arch in High Bridge, over the channel, has not seriously detracted from its appearance.

The old requirements of navigation made it necessary to have a clear height of 100 feet above the river, and the openings of 80 feet in width. The top of the parapet is 116 feet above high water, while there were originally eight semi-circular arches of 80 feet each over the river,

Camel-back Bridge Pekin China



Spectacle Bridge Japan

one arch of 50 feet in the Manhattan approach, and six in the opposite one. The structure was designed under John B. Jervis, Chief Engineer of the Croton Aqueduct.

The arch ring is finely accentuated, but, unfortunately, the tailing of the ring stones does not match with the courses in the spandrels. The piers, spandrels and parapets have a batter of 1 in. in 48, the width across on top of the parapets being 21 feet. The length of the piers is greater than the width of the arches, and counterforts are carried up with good effect. The belt course directly above the voussoirs is in entire harmony with the cornice above, which is formed by ornamental corbels supporting the coping, thus making a portion of the footways on each side.

The Spectacle Bridge or the Nishi O-tani at Kioto, Japan, is really the most notable stone bridge in the Orient, simply from the fact that it is of a different type of construction, so far as known, from any other bridge in the world, the two openings which give it its name, being complete circles. Whether or not the masonry was carried completely around and across the bottom for the purpose of paving the bottom, it is impossible to say, but it suggests that where in any new structure this is necessary, a solution is possible which is of aesthetic value. It is well to note that the spandrels are neatly constructed and coped by a single layer of stone. The roadway happily, is a vertical curve, presumably made so without any necessity, but from custom. The balustrade is neat, and of very good design; the lower half of each panel being nearly solid and the upper more open, while the posts are capped by an urn-like design, which is Oriental enough to please the most critical.

The Camel-back bridge in the Summer Palace Gardens at Pekin, China, is probably the most beautiful single span bridge of stone in existence. It is famed in Chinese nursery rhymes, as other famous bridges are in the songs of other lands.

"If you chance to be crossing the Camel-back Bridge,
Each step leads you up till you come to the ridge;
The lantern grass floats on the pond like a sail;
The silver fish bite at the gold fish's tail;
The big bellied frog sitting there on the rock
Keeps endlessly calling 'wahwa, wahwa!'"

STONE ARCH BRIDGES

Location	Date	Span	Rise	Ratio	Crown	Spr.	Remarks
Plauen, Ger.	1905	295.3	60.	4.9	4.9	11.2	Very Flat
Trieste, Austria		278.9	78.0	3.6	6.6	...	Mod. depth
Luxembourg	1901	277.7	101.7	2.7	4.7	...	Open Spand.
Montaugas		262.8	65.9	4.0	4.9	...	France
Trezzo, Italy	1380	251.0	88.0	2.9	4.0	7.0	Des. 1477
Walnut Lane	1907	233.0	70.3	3.4	5.5	9.5	Open Spand.
Sidi Rached		227.0	82.0	2.8	4.9	...	Algiers
Cabin John	1859	220.0	57.3	3.8	4.2	21.0	Aqueduct
Jaremcze	1892	213.0	59.0	3.6	6.0	10.2	Austria
Gutach, Bav.	1905	210.0	52.5	4.0	..	...	Twin Rings
Bogenhausen	1902	209.9	21.4	9.8	3.4	...	3 Hg. Flat
Thur Arch.		207.6	45.4	4.6	5.9	...	Switzerland
Grosvenor Dee	1833	200.0	42.0	4.8	4.5	7.0	England
Gour Noir	1888	196.8	52.8	3.7	5.6	13.8	Circular
Schwaenderholz		187.0	55.8	3.4	6.6	9.2	Railway
Coppel		187.0	55.8	3.4	5.9	9.9	German
Vieile Brioude		183.7	60.0	3.0	5.3	...	France
Ayr, Scot.		181.0	90.5	2.0	4.5	6.0	Railway
Wiesen.		180.0	68.0	2.7	5.9	...	Switzerland
Munderkingen		164.0	16.4	10.0	3.3	3.6	Very Flat
Navaur		160.5	65.0	2.5	6.3	...	France
Gignac.		160.0	44.0	3.6	6.5	...	France
Tyne, Eng.		159.9	79.9	2.0	4.6	...	Nr. N'wc'stle
Wheeling	1893	159.0	28.4	5.6	4.5	...	West Va.
London	1831	152.0	37.0	4.1	4.9	10.0	Elliptical
Gloucester, Eng.		150.0	35.0	4.3	4.5	...	Riv. Severn
Elyria, Ohio	1886	150.0	27.0	5.5	3.8	4.5	Freestone
Bellfield, Pa.		150.0	36.6	4.1	4.0	...	Pittsburgh
Turin, Italy		148.0	18.0	8.2	4.9	...	Mosca
Putney, Eng.	1886	144.0	19.3	7.5	4.2	...	Thames Riv.
Orleans, Fr.	1906	143.9	19.0	7.6	4.1	4.8	70 Spans.
Pont-y-Pridd	1750	140.0	35.0	4.0	2.5	3.5	Famous Old
Neuilly, Fr.	1773	128.2	32.0	4.0	5.1	...	Perronet
Maidenhead	1837	128.0	24.2	5.3	5.3	7.2	English R.R.
Souppes, Fr.	1886	125.0	6.9	18.0	2.7	3.6	Experiment'l
Waterloo, Eng.	1816	120.0	31.0	3.9	4.5	8.0	9 Spans.

The general design of this bridge is very fine, as the almost Gothic outline of the intrados is in perfect harmony with the curves of the parapet. The parapet rail or balustrade is simple yet pleasing, and fortunately a panel instead of a post is placed directly over the keystone. It is not overstating the case to say that there is no bridge, whatever its size, more striking or pleasing architecturally and in general appearance.

The nearly Gothic outline of the Camel-back Bridge is very pleasing, and as it seems almost certain that we are indebted to Asia for the principle of the arch, it is possible to go a step farther, and in studying the stone arch bridges of Persia, to say with a great deal of certainty that to Asia, and to Persia in particular, we are indebted for the Gothic arch. Dizful, on the River Riz, in the Province of Khuzistan, about 180 miles west of Ispahan, is the location of the bridge illustrated. There are twenty arches, three of which are shown. The piers are formed of rubble masonry with great spreading bases, and are nearly as thick as the span of the arches. The spandrels over the piers are lightened by the small arches, and add to the architectural effect, if such a rough structure can be said to be an architectural creation. Dizful is also noted for its nearly two score sacred tombs, and nearly as many mosques. The ruins of ancient Susa are only a short distance away.

Vanderbilt Estate Bridge

Forest Park Arch, St. Louis

CHAPTER IV.

DESIGN OF CONCRETE BRIDGES.

The designing of concrete bridges has become very much of a specialty, inasmuch as such bridges, being of a monolithic character and not formed of separate blocks as is the case with stone bridges, lend themselves more readily to decoration by molding and ornamental details. The ones which do not have such decoration, but which are severely plain, are generally, in the author's opinion, the most pleasing, especially when they conform to the fundamental principles of simplicity, symmetry, harmony, and proportion, as already enunciated, and when they conform to the basic principle of having an odd number of spans, and an odd number of spandrel openings for each span or half span.

The details adopted should proclaim them as monolithic structures, and no divisions of the arch rings to indicate separate voussoirs, nor such divisions to indicate separate blocks in the spandrels or piers. Neither should stone facings be used on a concrete or reinforced concrete bridge, but the entire structure should be truth telling in every respect. Moldings on the arch ring, ornamental keystones or dentils, and ornamentation of piers are usually very pleasing in concrete spans of one hundred feet or under, but they should be of a simple and chaste character, and if used for longer spans they should be of very severe character, and very carefully studied for their effect upon the ensemble.

The method of reinforcing concrete arches often has a vital part in their continued artistic effect, as those with a minimum of bar reinforcing do not always retain their shape or solidity, which is a vital part in their architectural appearance. Those with heavy bar reinforcing usually retain their shape and solidity, but those with riveted or structural reinforcing will come nearest to retaining their monolithic characteristics. Therefore it would seem best to make all shorter concrete spans of heavy monolithic concrete without any rein-

Reno Nevada Arch Bridge

Goat Island Niagara

forcing, as was done for the Connecticut Avenue Bridge in Washington City. This bridge is without question one of the best examples of engineering architecture in the world. There are five main spans of 150 feet with 75 feet rise, and a thickness at the crown of 5 feet, with one approach span at either end. Each one of the main spans has three well proportioned spandrel arches on each side of the center. The piers are surmounted with a shaft having pilasters in relief, while the abutments are solid, and in keeping with the entire design. The balustrade, pylons and entrances of the bridge are very carefully designed to harmonize with the whole structure, and will be described in the chapter covering bridge details, as they form a very important part in the design of all bridges, especially those of concrete.

The Monroe Street concrete arch bridge forms a crossing of the turbulent Spokane river. It was designed by the late J. C. Ralston, M. Am. Soc. C. E., and has a main span of 281 feet. When the fill was completed on the right of the view, the main bridge showed as a very finely designed piece of bridge architecture, but the whole was somewhat marred by the long approach at one end. The building of a high steel railway viaduct over this approach still further detracts from the artistic appearance of this most notable and monumental structure.

The Walnut Lane concrete arch in Philadelphia has a span of 233 feet and a rise of 70.3 feet. The arch ring is 3.3 feet thick at the crown and 5.5 feet thick at the springing. The simplicity of the entire design is notable, and with the setting of the surrounding scenery it is quite artistic, although a strict adherence to the fundamentals of design might have made it a more outstanding structure.

The monolithic concrete bridges, without any reinforcement whatever, approach most nearly to the stone bridge for solidity and that massiveness of appearance which is so satisfying to the observer. The rapid development of concrete-steel construction has led to the building of bridges of this type in every section of the world, but it is to be deplored that so many have been built of such very light sections, with too much dependence being placed upon theoretical considerations, and not enough attention having been paid to the practical

EDWIN THACHER

details of construction. The bids at some lettings of large concrete-steel bridges vary quite widely, indicating that some of the bidders have a very much greater confidence in the theory, and perhaps in the material to be used, than have others. The slight depth necessary for the arch ring at the crown is very often a great advantage, when the clearance between water line and floor level is small, but there is danger, from the architectural standpoint, of getting the proportions so attenuated as to spoil the artistic effect.

The readiness with which concrete lends itself to being molded into artistic forms as already suggested, provides a great temptation for the engineer or architect designing a concrete bridge to use frivolous details and too much ornamentation, thus spoiling many structures which would, if more plainly designed, be very creditable. Many small and medium sized bridges are simply bad copies of notable stone arches, the details of which were appropriate enough in their places, but entirely unsuitable for the smaller structures. It must, therefore, be considered better from the esthetic viewpoint, to design a plain and wholesome structure than to make a bad copy. Let the engineer be humble enough to consult with others having good artistic ideas, when designing a notable masonry or concrete bridge, unless perfectly sure of the plan being entirely fit.

The bridge on the Vanderbilt Estate, at Hyde-Park-on-Hudson, is one of the most chaste designs that has been made for a concrete bridge. The span is small, being only 75 feet in the clear, while the rise is 14 feet 8 inches, and the roadway 16 feet. The depth of the arch ring is but 15 inches, and has led to the most serious fault in the design, namely that of making the depth too slight from the intrados to the top of the coping. The paneling of the spandrel walls, while it would be out of place on a large bridge, is appropriate enough for a small one. The relief afforded to the arch by setting out the side walls of the abutments is very pleasing, and the joggled work at the offset is in entire harmony with the design. The balustrade with turned balusters is very neat, and accords well with the entire conception. The bases of the balustrade and of the posts were molded in situ, but the balusters and top-rail were cast in forms and afterwards set in

Zanesville Ohio Y Bridge

Topeka Kansas Bridge Thacher

Pont sur L'Oued-Mellegue Tunis

place. The bridge is built on the Melan system, being reinforced with seven 9 inch steel I-beams. The concrete for the arch ring was composed of 1 part of cement, 2 of sand, and 4 of broken stone; while for the wing-walls, abutments, and spandrel walls a concrete of 1 part cement, 3 of sand, and 6 of broken stone was used.

An art center like Cincinnati, Ohio, would naturally be expected to supply a notable example of an artistic masonry bridge, and the one illustrated and located in Eden Park, is certainly a very beautiful structure. The arch ring is neatly accentuated by the moldings, the ornamented keystone, and still further by the paneled spandrel walls, which is all appropriate for a short span. The abutments are well designed and well proportioned, being allowed to project enough to give the impression of the substantial abutments required to take up the thrust of such a flat arch. The paneling of the wing walls is the most inappropriate part of the design, as the dying away of the panels in the ground is in bad taste. The highly ornate design of the balustrade is very pleasing for a purely ornamental structure, and the details are exceedingly well proportioned. The span of the arch is 70 feet, the rise 10 feet, and the total width of the bridge 32.5 feet. The roadway is 18 feet in width and the sidewalks 5 feet each. The arch is 15 inches thick at the crown and 48 inches at the spring, reinforced with 9 inch 21-lb. I-beams, spaced 36 inches apart.

One of the most unique concrete bridges in the world is the "Y" bridge at Zanesville, Ohio. It was built to take the place of a wooden bridge of the same ground plan, at the confluence of the Licking and Muskingum rivers. The bridge is of good design, being a plain, massive, monolithic structure, well suited to the location. The piers are of plain design, with rounded ends, and coped with a single course. The elliptical arches are perfectly plain, as are also the spandrel walls and the balustrade. The structure is relieved by the semi-circular counterforts over each pier, which are carried up above the balustrade, to relieve that as well. The design, while such as might have been made in mediaeval times, is very harmonious, and the bridge one of the most pleasing that has been built of concrete.

The spans in the long arm of the bridge are all 122 feet in length, the first having a rise of 11.5 feet and the others of

Walnut Lane Arch Philadelphia

Monroe Street Spokane Arch

14.6 feet. The arm with two spans has one span of 120.6 feet with a rise of 11.5 feet, and one span of 99 feet with a rise of 6.28 feet. The spans in the other arm are all 81 feet, with rises of 14.6 feet and 6.06 feet, respectively. The thickness of the arch rings varies from 18 inches for the shortest span to 30 inches for the longest. Each span is reinforced with 15 pairs of steel bars of the Thacher type, ¾-inch in thickness and varying in width from 3 to 5 inches, the bars being placed 2 inches from the top and bottom of the arch ring and 36 inches apart transversely. The concrete for the arch ring was composed of 1 part cement, 2 parts of sand and 4 of stone. The entire structure was carefully built under a detailed specification, and is one of the best examples that has been carried out.

The largest, at the time it was built, and one of the first concrete-steel bridges to be constructed in the United States was that built by Edwin Thacher at Topeka, Kansas, over the Kansas River. There are five spans, the central one being 125 feet in length, the two adjoining ones 110 feet each, and the shore spans 97 feet 6 inches each. The roadway is 26 feet wide and the sidewalks 7 feet each. The piers are comparatively plain and of very neat design. The arch rings are well defined, but the spandrel walls would have been much more pleasing if left plain, than with the possibly inappropriate paneling that was used. The counterforts over the piers relieve to some extent the flatness of the face of the structure, but would have been better if more prominent, as are those over the abutments. The brackets and consoles supporting the coping are appropriate, but a plain balustrade would have been much better than the lattice railing, which detracts much from the effect of solidity which the structure should have. At any rate, the solid masonry balustrade should have been carried to the end of the wing walls.

There may possibly have been some reason for the broken grade line, but the effort should be made in every masonry bridge to make the grade line a gentle curve. The general appearance would have been improved by lamp clusters over the piers and abutments, which were originally arranged for, but which were omitted when the bridge was built. The general arrangement of the bridge, its division into five spans, and its general proportions are good; but it will always be

Connecticut Avenue Washington

Eden Park Arch Cincinnati

wise for the designer to take care that an otherwise good design is not marred by the omission of some vital features and by the use of inharmonious details.

The location of the Goat Island bridge between the mainland and the island above Niagara Falls, is an ideal one for a concrete or masonry bridge. The structure consists of three spans, one of 110 feet and two of 103.5 feet, and is built on the Thacher concrete system. The engineer can profitably take some time to study the bridges at Niagara, both above and below the Falls. The graceful steel arches of long span are especially appropriate for spanning the gorge, adding to the grandeur and impressiveness of the scenery, while the masonry bridge illustrated is in entire harmony with the low banks and the inert force of the waters before they leap over the Falls into the gorge. In perfect harmony, too, are the rock facing, the thick piers, and the solid balustrade, yet the structure should have been a solid stone bridge and not a pretended one, so it is an example of what not to do in any location, and more especially at this site.

The concrete-steel bridge in Forest Park, at St. Louis, is another example of the possibilities of this type for the ornamental structures required in parks. The span is only 60 feet, the rise 15.5 feet, and the thickness of the arch ring 11 inches at the crown. The arch is built on the Melan system, with eleven 8 inch steel beams as reinforcement for the 32 feet width of the bridge, the roadway being 24 feet and one sidewalk 6 feet in width. The abutments are made of concrete with 1 part cement, 3 of sand, and 6 of broken stone; the spandrel and wing walls of 1-2½-5 concrete, and the arch ring of 1-2½-4 concrete.

The intrados of the arch is tastefully molded, and the spandrels and abutments are paneled. The design is somewhat marred by the two molded rings in the spandrels and by the heavy balustrade post which is bracketed out at the center. Here again is an example of where the roadway and balustrade should have been on a gentle curve from end to end of the bridge. The balustrade itself is of good design and in harmony with the bridge.

The bridge at Reno, Nevada, is of quite harmonious design, and, although consisting of two spans, instead of one or three, of only 65 feet each, is worthy of discussion. The curve of

Proposed Sullivan Gulch Bridge

Styer Austria Concrete Arch

CONCRETE ARCH BRIDGES.

Location	Type	Span	Rise	Ratio	Crown	Spring	Remarks
Rome, Italy	Re.	328.1	32.8	10.0	0.94	..	Tiber River
Grafton, New Z	Re.	320.0	90.0	3.5	5.5	..	3 Hinged
Langwitz	Re.	315.0	137.8	2.3	4.0	..	Switzerland
Larimer Ave.	Re.	300.4	67.0	4.5	6.5	..	Pittsburgh
Halen, Switz.	Re.	286.0	112.0	2.6	3.8	..	Deep
Monroe Street	Pl.	281.0	115.0	2.4	6.75	..	Spokane
Rocky River	Pl.	280.0	79.1	3.5	6.0	..	Cleveland
Gmunden, Switz.	Re.	259.3	87.0	3.0	4.1	..	Sitter Arch.
Walnut Lane	Pl.	233.0	70.3	3.3	5.5	..	Philadelphia
Kempten, Bav.	Pl.	211.5	87.6	2.4	4.3	6.5	Basket Handle
Meadow Street	Re.	209.0	46.1	4.5	5.0	..	Pittsburgh
Colorado Street	Re.	204.0	77.4	2.9	3.7	..	Pasadena
Almandares	Pl.	190.0	32.5	5.9	5.5	..	Havana
Lautrach, Bav.	Re.	187.5	32.2	5.8	..	..	Iller Riv.
Neckerhausen	Pl.	165.0	13.5	12.2	2.8	..	Germany
Chattellerault	Re.	164.0	15.8	10.4	1.8	3.0	France
Connecticut Ave.	Pl.	150.0	75.0	2.0	5.0	..	Washington
Alma, Paris	Pl.	141.0	28.0	5.0	4.9	..	Rubble Con.
Big Muddy	Pl.	140.0	30.0	4.7	5.0	..	I. C. Ry.
Piney Branch	Pl.	125.0	39.0	3.2	5.0	7.7	Washington
Jacaguas Riv.	Re.	120.0	12.0	10.0	2.3	..	Porto Rico
Napoleon, Paris	Pl.	116.0	14.8	7.7	4.0	..	Rubble
Miltenburg	Pl.	112.0	17.7	6.3	2.5	2.8	Germany
Laibach Bridge	Re.	102.8	14.6	7.1	..	..	Austria
Venice, Cal.	Re.	96.0	13.8	7.0	2.1	3.0	Elliptical
Yorktown	Re.	95.0	11.1	9.4	..	..	Indiana
Dayton, O.	Re.	88.0	8.0	11.0	1.7	..	Miami Riv.
Santa Ana	Re.	86.0	36.9	2.1	3.5	..	California
Belvidere	Re.	81.0	10.5	7.7	3.0	4.6	Illinois
Clifty Creek	Re.	80.0	12.0	6.7	1.3	..	Indiana
Grand Rapids	Re.	79.0	11.0	7.3	1.5	2 5	Indiana
Gayo River	Re.	70.0	7.5	9.3	..	..	Porto Rico
Sandy Hill	Re.	60.0	8.5	7.1	1.8	2.5	Hudson
Decatur	Re.	59.0	...	..	3.8	..	Illinois
Como Park	Re.	50.0	12.5	4.0	0.8	2.5	St. Paul
Railway Arch	Re.	30.0	9.0	3.3	2.8	6.4	Ohio

the intrados is very graceful and suited to give plenty of waterway. The arch ring has more depth than is usual in a concrete-steel arch, and the outlining of the arch ring and arch stones, while inappropriate, adds to the appearance of the structure. The curve of the batter lines of the piers is a very good detail, and the solid base used for the parapet railing, excuses in some measure the use of the metal railing on the upper portion. The lamp clusters over the piers and abutments add enough to the architectural effect to well repay the slight addition in cost. The bridge is constructed by using corrugated reinforcing bars, spaced to conform to the stresses in the various portions of the bridge.

The system of concrete-steel construction is adapted to long spans with very little rise, and the bridge at Steyer, Austria, is shown simply as an example of the extreme to which the method can be carried. The arch is built on the Melan system, with a span of 138.4 feet, a rise of 9.4 feet, and thicknesses of 2 feet and 2.3 feet at the crown and springing, respectively. The arch ring is mistakenly made prominent by being blocked off to represent ring stones, while the remainder of the structure is of very indifferent design. In a few words, the bridge is another example of what can be done, and what not to do.

The Pont sur l'Oued-Mellegue in Tunis is of 301.76 feet span, and a type of structure much in favor with French engineers. The design is after the System Henry Lossier, and while there is no extraneous ornamentation, unless the arched portal is so considered, its simplicity and internal harmony are more satisfying than any decorations of the usual type would lend to such a great concrete span.

The design for an arch bridge over Sullivan Gulch at Portland, Oregon, was carried out by the engineers to fulfil the author's ideas as previously outlined herein, and the result was very satisfactory in every respect except as to the apparent need for footings for the slender piers of the approach spans. Then too the appearance might have been improved by using five spandrel arches over each half of the main arch ring, instead of the chain of spandrel arches extending across the crown of the arch.

CHAPTER V.

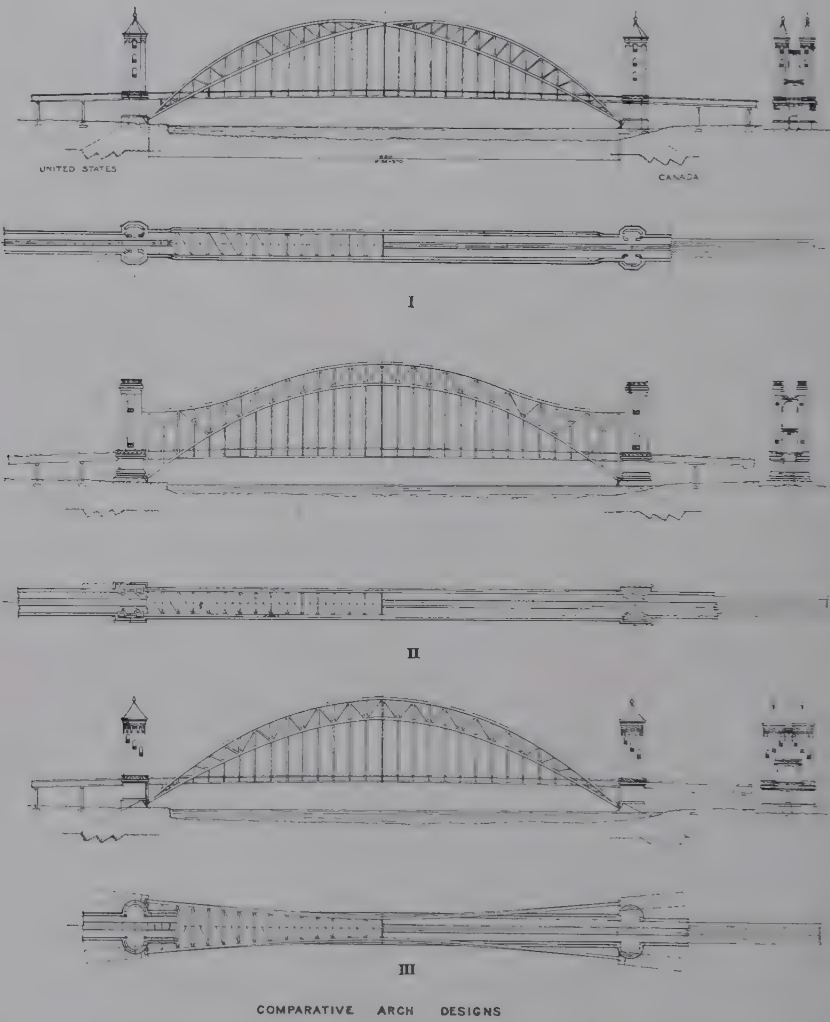
DESIGN OF STEEL ARCH BRIDGES.

The fundamental principles in the design of steel arch bridges, are of necessity fixed by the theoretical considerations, and by the fundamentals as already outlined for all works of engineering architecture. The analysis of steel arches, made by the author some years ago, developed the fact that there were eighteen different distinct types, most of which are however variations of the five basic types, no hinges, one hinge, two hinges, three hinges, and cantilever arches.

(a) Arch ribs with no hinges, plate girders;
(b) Arch ribs with no hinges, lattice ribs;
(c) Arch ribs with no hinges, trussed ribs;
(d) Arch ribs with one center hinge, plate girders;
(e) Arch with one center hinge, spandrel-braced;
(f) Arch with two hinges, plate-girder ribs;
(g) Arch with two hinges, trussed ribs;
(h) Arch with two hinges, spandrel-braced;
(i) Arch with two hinges, lattice ribs;
(j) Arch with three hinges, plate-girder ribs;
(k) Arch with three hinges, lattice ribs;
(l) Arch with three hinges, trussed ribs;
(m) Arch with three hinges, spandrel-braced;
(n) Arch with three hinges, and fixed ends;
(o) Arch with three hinges, no center depth;
(p) Arch with five hinges, spandrel-braced;
(q) Cantilever arches, three hinges;
(r) Arched cantilevers, two hinges.

The ones which are fundamentally best artistically to form an integral portion of a work of engineering architecture are,

(b) Lattice ribs with no hinges.
(e) Spandrel braced with one hinge.
(i) Lattice ribs with two hinges.



Detroit Comparative Designs Fowler

(h) Spandrel braced with two hinges.
(k) Lattice ribs with three hinges.
(m) Spandrel braced with three hinges.
(q) Cantilever arches with three hinges.
(r) Arched cantilevers with two hinges.

The table by the author of one hundred arches which have been built or designed, was published in volume 83 of the Transactions of the American Society of Civil Engineers, as a discussion of the Economics of Steel Arch Bridges, and no one should design a steel arch without making a very careful study of this table. The great two hinged spandrel braced arch of 1650 feet span of the Hell Gate arch bridge type, has been put under construction at Sydney, Australia, since the tabulation was made, and the slightly longer lattice rib arch of 1675 feet span, by Ammann over Kill von Kull at New York

THE KILL VON KULL ARCH
O. H. AMMANN CH. ENG. L. S. MOISSEIFF ASST. ON DESIGN

is also begun. The author has recently made designs for a 1200 feet three hinged arch of the Fidler type, and also complete designs for a span of 1650 feet, and a general plan for one of 1850 feet of the same type.

The fact that most arches are built as deck structures, usually makes any ornamentation of the arch itself unnecessary, and most of the artistic effort may be expended upon the masonry, balustrades, and entrances. When however the arch is built of the through or half through type, much more attention must be paid to the form and detailing of the arch itself, and towers should be used at either end, and upon intermediate piers to give the proper proportion to the structure, as well as to produce a real design of engineering architecture.

Gustav Lindenthal

The towers of the Hell Gate Arch may be cited as an outstanding example of such a design, while those of the Bonn bridge over the river Rhine, and those of the Sydney Harbor Arch are also very pleasing, appropriate, and chaste designs.

The most pleasing outline yet made for a through steel arch bridge, is that of the Hell Gate Arch over East River, designed and built by Lindenthal. The reverse curve in the top chord at the ends, was used because of the need for more depth at the ends for portal bracing, and to properly care for the stresses. This resulted in the outline, from theoretical considerations very largely, which is very nearly a parallel

HELL GATE ARCH BRIDGE

to the outline of the Stone Camel-back bridge in the Imperial palace grounds at Peking, China. The outline of this oriental bridge resulted in the need for a high arch for navigation clearance, but as only foot traffic was to be cared for, the curve of the top or deck, was reversed at the ends to approach the ground quickly, or entirely as a means to care for practical considerations.

The most common error in the designing of a deck steel arch bridge, is the lack of a proper visual backing when the arch does not spring directly from the abutments. The most prominent examples of this are to be seen in the upper and lower arch bridges at Niagara; the one at the Falls, and the other at the head of the Rapids. In both cases the shallow deck approach spans give an appearance, or impression of very little backing for the thrust of the great arches, but the

Colebrookdale Arch England 1779

Southwark Bridge London

ones at the Falls are open to the most severe criticism, as they are merely bow string deck trusses. The Market Street Arch at Youngstown, Ohio, designed and built by author, had very similar conditions, and extra deep straight approach spans were employed, with the subtrussing of the same depth as the trusses of the arch, so that a result, while not perfect, but much more pleasing was obtained. The members of any arch must be proportioned to give pleasing effect, with some members having small stresses made deeper than called for by economy, and others with large stresses made as small in side elevation as possible, so as to keep all members harmonious

Sydney Arch Australia

as to the gradation of visual sizes. This is especially necessary in the web members of a Fidler arch where the stresses are proportionately less than in many other types of steel arches. The gusset plates of riveted arches of medium and small span, may be curved out to give a more pleasing effect, as strain gauge readings made by the author show that no appreciable stresses exist in the edges. This curving out may now be done very cheaply by using cutting torches to cut out the curves. The results in steel arch design obtained by many designers have been very pleasing, notwithstanding the fact that in the past no code of engineering architecture has existed, but the intuitive sense of beauty which some possess,

Market Street Arch Fowler

Niagara Railway Arch Buck-Fowler

has caused the simplicity of design so to fuse with symmetry, harmony, and proportion, that those structures which are nearly correct examples may be readily selected.

The earliest metal arch bridges were those of cast iron, built in England. The one at Colebrookdale over the river Severn of 100 feet 6 inches span, was built in 1779, and that at Wearmouth in 1796. Soon after this Napoleon caused three

ALEXANDER III BRIDGE PARIS

iron bridges to be built over the Seine in Paris, the original Pont de Austerlitz, the Pont des Arts, and the Pont Jardin du Roi. While none of these bridges had any real pretentions to being works of engineering architecture, they represent the beginnings of metal arch bridges, and were naturally more pleasing than some other types. The Southwark Bridge over the Thames at London, has cast iron voussoirs, and with lattice spandrels was of very pleasing design. The bridge of the Caroussel in Paris, built about 1834 was of three spans, and may be classed as really artistic in most respects, with the

BONN BRIDGE OVER THE RHINE

LUIZ I BRIDGE OPORTO PORTUGAL

spandrels filled with five circular rings in each half arch, of lessening size as the center of each was approached. The great number of cast iron arches built during the first half of the nineteenth century, makes it advisable for the modern designer to give them careful study, when planning a steel arch, as very many ideas can be thus obtained which comply fully with basic artistic principles.

The numerous iron or steel arches of Europe built about the middle of the last century or later, are many of them very good in design. The Arcole bridge at Paris built in 1855, of 262 feet 6 inches span, has the quite small rise of only 20.2 feet. The ribs are of riveted plate girder type, 4.5 feet deep at the springing and less than 2 feet at the center. The same type of arch was employed for the Alexander III bridge over the Seine, built in 1899 with cast steel voussoirs, with a span of 352 feet and the notably small rise of 20.6 feet! It is difficult to decide as to the real merit of this structure architecturally, as most of the artistic work was done on the masonry, and the very elaborate entrances and parapets. However it is not a type of design that will often if ever be repeated, except under like conditions of environment.

The railway arch bridge of three spans over the Rhine at Coblentz, was built in 1863 and has beautiful lattice ribs of 348 feet span. The river piers are of neat and chaste design, while the rectangular mediaeval entrance towers are quite monumental. The Eads bridge over the Mississippi at St. Louis is very much a replica of the Coblentz bridge, with lattice ribs of 502 feet spans for the side arches, and 520 feet for the center. The piers are of much finer design, while the stone approaches are nearly all that could be desired to make the structure a true piece of engineering architecture. These approaches are described in a later chapter. The Washington Arch bridge over the Harlem at New York, while of the plate girder type, has only two spans of 510 feet each, thus making it fundamentally a failure architecturally, and its appearance is still further marred by the unbalanced approaches. However the very beautiful masonry of the piers and approaches, and the beautiful balustrades, proclaim it to be artistically beyond the ordinary, so that it should receive most careful study.

White Pass Alaska Arch Fowler

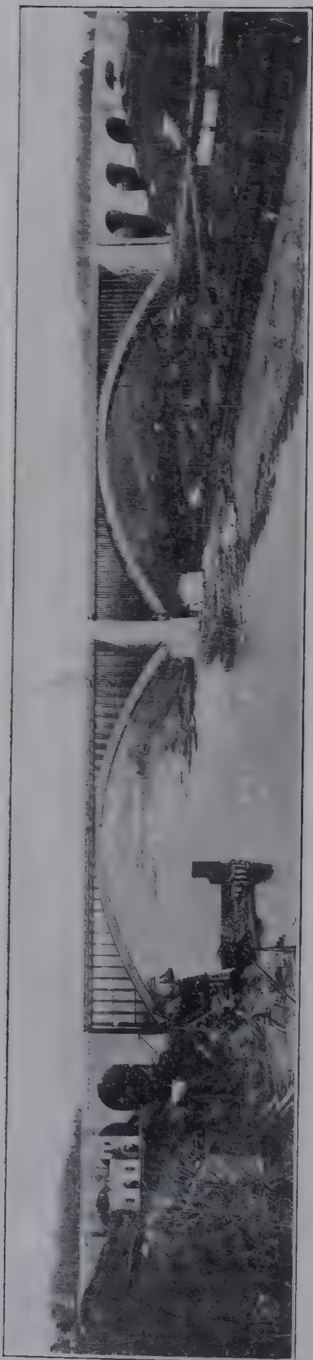
Stony Creek Arch Canada

The Rhine bridge at Mayence built in 1885, is a beautiful one of five spans with lattice ribs, most carefully designed artistically. The masonry of the piers is cut stone work of much fine detail, surmounted by light pylons of fine design, carrying two lights on brackets. The entrances are flanked by neat cut stone gate houses with segmental domed roofs and finials. The approaches are short span stone arches. The Bonn bridge over the Rhine is another German bridge of nearly perfect design, consisting of a large through center

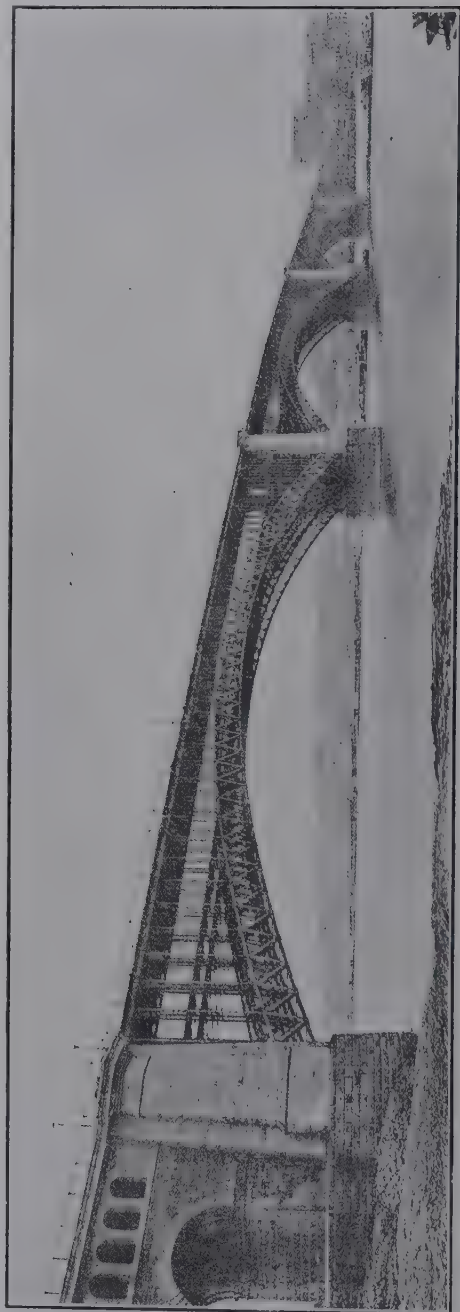
White Pass Arch Erection Fowler

steel arch of 307 feet span, flanked on each side by a steel deck arch span. The piers of each end of the main arch carry most elegant stone towers of mediaeval design. Except for the fact of the unbalanced approaches, it complies with all of our fundamental principles.

The great arches of single span have already been mentioned, but the one of Luiz I at Douro, Portugal, of 565 feet span is a very striking and pleasing structure, carrying a roadway near the level of the springing and another over the crown of the arch about 150 feet above. It is a lattice rib with no hinges, 26 feet deep at the center and 55 feet deep at the springing. More impressive than this is the great arch of the Garabit viaduct in France, which has two hinged sickle



THE WASHINGTON BRIDGE OVER THE HARLEM



ST. LOUIS EADS BRIDGE OVER THE MISSISSIPPI

shaped lattice ribs of 541 3 feet span, with a rise of 186.6 feet. The shape of the arch ribs and the graceful design of the superimposed viaduct, makes one forget the usual need of deep flanking spans. The Kornhaus Arch at Berne, Switzerland, is another high one of the same type, which has been most pleasingly coordinated in all phases of design. The lattice ribs of 377 feet span have no hinges, with a depth at the springing of 18.8 feet, and only 5.3 feet at the crown.

The Stony Creek deck arch in Canada, of 337 feet span, has lattice ribs, and is among the most notable of American bridges of this type, with only the usual steel bridge details. The White Pass and Yukon Railway arch in Alaska, built by the author in 1900, is a very unusual type of arch, inasmuch as the bottom chords are inclined rafter like members, but with a total span length of 400 feet and 250 feet above the bottom of the gorge, it harmonized well with the surroundings, so that its sheer simplicity makes it a somewhat pleasing structure, which fulfills all of our basic conditions. The full measure of compliance with the four basic postulates, is best shown in the design of the Knoxville, Tennessee, Arched Cantilever bridge, designed and built by the author and which was the beginning of this idea for an engineering architecture.

The City of Knoxville desired an arch bridge over the Tennessee river to replace the old Howe truss which had served for many years, and the stone bridge design was made as illustrated. The cost proving excessive, the steel arched cantilever was designed as one equally beautiful and of great durability. The design for stone bridge violated one of the most important principles in using an even number or four spans, and the pier in the center was made more unpleasing by making it very thick for an abutment pier. The design was also unbalanced by having an arched approach at one end, and a plain abutment at the other end. The circular openings to lighten the spandrels were not wholly unpleasing, but spandrel arches would have been better, more graceful, and of greater beauty. The arched cantilever on the other hand was of extreme simplicity; of five spans perfectly symmetrical and balanced; in entire harmony in all parts and with the natural beauties of the location; and the theoretical proportions as correct as possible for five arched openings. There-

Garabit Viaduct France

Kirchenfeld Berne Switzerland

fore these two designs shown together constitute a quite complete comparison as to what to do and what not to do in a bridge design. (see pg. 50)

The rise of an arch has much to do with its pleasing appearance, and it should not be made greater than one fourth if possible, nor less than one seventh. In other words, given a certain type of arch, the rise must be selected as nearly as possible in the same way that the depth of a truss is found, that is, deeper for the heavier and dynamic loadings. Where one-sixth rise might prove enough for producing a stiff structure for the light loading of a highway arch bridge, it would need to be increased to one-fifth, or perhaps to one-fourth, or more, for heavier loading and for railways, using the engineer's judgment for preliminary layouts to form the basis for investigations. This, therefore, does not agree fully with the author's findings. Judgment alone would have indicated that the Washington Bridge over the Harlem should have had a greater rise than 18% if in any way possible, or, the girders should have been deeper, and thus have avoided in large measure the vibration or bouncing of the structure caused by the live loads. The rise necessary to overcome this would have been much greater than the economical rise found by the author, or probably 25% of the span, or greater. The ultimate limit of economy should not be considered as the only thing to be attained, but the aim should be to design a structure that will be stiffer and therefore more lasting, without, of course, adding any undue increase in cost. The Alexander III Bridge, in Paris, is an even more flagrant example of a too shallow arch, and, with a rise of only one-seventeenth, the vibration, of course, is as predominant as it is lacking in arches of possibly too great rise, like the author's White Pass, Alaska, arch, or the St. Croix, Minn., arch spans. The investigation as to the last word in economy for a given crossing, may prove to be an almost endless task, unless the engineer, from long experience, can single out two or three types which are quite sure to prove suitable. The chance of making an error therefore, would seem greater in the selection of the type, than the possibility of serious error in proportions. It is the author's opinion that the economic depth can be varied 5% either way, without much exceeding the computer's most

The Kornhaus Bridge at Berne

Mill Creek Park Arch Fowler

probable percentage of error in making an estimate from a stress sheet, plus the variation of sectional area, which may easily total 5 per cent.

Where the possible rise below grade would make the arch too flat for rigidity, as in numerous cases listed, notably the Alexander III Bridge, the Washington Bridge, the St. John Bridge in Canada, and the design for an 1,888-ft. arch at Quebec by Worthington, then a half-through type of arch would be preferable. Although the vibrations from the live load are not all due to the small rise, as has been shown in truss spans of extra depth built by the author, where the bouncing could only be attributed to the inertia of a heavy paved floor, the greater rise recommended is certainly advisable.

Where there is a greater depth below grade, than is required for economical rise, the economy of the structure is but little changed by making the rise proportionately great, leaving no more in any case, than room above the crown of the arch for a distributing truss, if it is to be used, and not carrying the roadway directly by long posts, which are unsightly when they extend above the crown of the arch rib. The designers of the Viaur, Cleveland, Luiz I, Mungsten, Garabit, Pia Maria, Kornhaus, St. Croix, White Pass, Blauw-Krantz, Youngstown, Fern Hollow, Namti, and Surprise Creek Arches evidently found this method of design most artistic, and fairly economical, or they would not have used such proportions. The speaker has in mind no actual cases which would indicate a contrary view.

Wherever possible the rise should be greater than indicated by theory or ordinary practice, especially in the case of railway arches or those for heavy highway loads, and it is found that twenty-four of the arches in the table, have a rise of practically 25.0% or greater, and eight of these have a rise greater than 30.0 per cent. The study of individual cases indicates that the rise should seldom be less than 20.0%, and should preferably be 25.0% or greater, in the interests of stiffness and consequently longer life of the structures carrying the heavier loadings.

Where the best bridge is desired, that is, the one with the greatest ultimate economy, and not the cheapest in first cost,

STEEL ARCH BRIDGES.

Location	Type	Span	Rise	Ratio	Rib	Width	Designer
Hudson River	Hy.	2850.0	440.0	6.5	100.	150.	Max Am Ende
Detroit River	H&R	[illegible]	370.0	5.0	75.	84.	Fowler
Quebec, Can.	Ry.	1500.0	164.0	9.1	42.	D.T.	Worthington
Kill von Kull	Hy.	1675.0	266.0	6.3	38.	66.	Ammann
Sydney, Austr.	Hy.	1650.0	330.0	5.0	66.	66.	Fowler
Sydney, Austr.	Hy.	[illegible]	400.0	4.1	60.	66.	Bradfield
New York City	Hy.	[illegible]	240.0	5.0	48.	60.	Fowler
New York City	Ry.	977.5	220.0	4.4	140.	4T.	Lindenthal
New York City	Ry.	977.5	235.0	4.2	60.	4T.	Lindenthal
Kentucky Riv.	Ry.	[illegible]	162.5	5.3	50.	D.T.	Lindenthal
Niagara, N. Y.	Hy.	840.0	150.0	5.6	26.	46.	Schneider
Viaur, France	Ry.	722.0	176.2	4.1	88.	...	Bodin
Niagara, M. C. Ry.	Ry.	640.0	105.0	6.1	20.	2T.	Deimling
Vilaine, France	Hy.	629.9	150.0	4.2	38.	...	Lebert
Bonn, Ger.	Hy.	614.0	97.0	6.4	35.	...	Krohn
Duesseldorf	Hy.	594.7	90.5	6.6	35.	...	Krohn
Needles, Cal.	Ry.	592.0	100.0	5.9	19.	...	Sourwine
Cleveland, O.	Hy.	591.0	144.0	4.1	91.	...	Felgate
Luiz I Douro	Hy.	566.0	146.4	[illegible]	55.	2DK.	Seyrig
St. John, N. B.	Ry.	560.0	60.0	9.3	60.	...	Schneider
Mungsten, Ger.	Ry.	557.8	241.0	2.3	39.	1T.	Rieppel
Niagara, G. T. R.	H&R	550.0	114.0	4.9	20	2DK.	Buck & Fowler
Garabit, Fr.	Ry.	541.3	186.6	2.9	32.	1T.	Banby
Rockingham, Vt.	Hy.	540.0	90.0	6.0	14.	...	Worcester
St. Louis, Mo.	H&R	520.0	77.8	6.7	19.	2DK.	Eads
Washington, N.Y.C.	Hy.	510.0	91.7	5.6	18.	...	Hutton
Zambezi, Africa	Ry.	500.0	90.0	5.6	105.	2T.	Fox
Paderno, Italy	H&R	492.0	122.8	4.0	23.	...	Rothlisberger
Austerlitz, Paris	Ry.	460.0	65.6	7.0	7.	...	Lavallois
Kornhaus, Switz.	Hy.	377.0	103.0	3.7	19.	...	Arthur
Alexander III.	Hy.	352.6	20.6	17.0	5.	...	Resai
Mayence, Ger.	Hy.	341.0	32.8	10.4	7.	...	Nurnburg
Stony Crk., Can.	Ry.	337.0	80.5	4.2	30.	1T.	Peterson
Spokane, Wash.	Ry.	255.0	33.9	7.5	43.	2T.	Fowler
Knoxville, Tenn.	Hy.	242.0	30.0	8.0	20.	42.	Fowler
White Pass, Alaska	Ry.	240.0	90.4	2.7	0.	S.T.	Fowler
Salem, Oregon	Hy.	240.0	41.0	5.8	8.8	32.	Fowler

it will usually be found economical, and sometimes artistic with a deck structure, to build it with a rise greater than 25.0%, and often up to 40.0% or more, when there is room below grade; or even for a half-through arch when it would not prove to be top heavy. Where the possible rise is materially less than 17.0% for heavy loading, some other type than a deck arch should be used, or the idea of an arch should be abandoned and a structure of an entirely different type designed.

The depth of rib, or center depth, should only be from 3.0 to 4.0% of the span length, except in the case of solid ribs, where the depth might be as small as 2.5%, but never less than 2.0%, unless for some unavoidable reason, and greater than 2.5% for spans of small rise. The end depth of ribs without hinges, of course, must be greater than at the center or crown, as required by the stresses, but, for appearances, never less than one and one-half times the center depth, and usually not less than two and one-half times. The greatest ratio is four times, as in the great Mungsten, no-hinge, lattice-rib. The center depth of spandrel-braced arches has varied all the way from 0.0 to 8.5%, but a depth of about 4.0% would seem to be economical and artistic, and a depth as great as 7.0 or 8.0% would often be decidedly displeasing.

The center depth of three-hinged ribs is perhaps more pleasing when not less than the greatest depth of the rib, but such a design is not the most economical. The center hinge in a spandrel-braced arch has been placed almost always in the lower chord, and this is a much better location, especially with respect to detailing the structure.

John Augustus Roebling

CHAPTER VI.

DESIGN OF SUSPENSION BRIDGES.

The suspension bridge is as inherently beautiful as the arch, but more easily ruined in its artistic appearance by errors of commission and omission in the observance of the necessary fundamental details of design which lead to a pleasing ensemble. The curve taken by the unloaded cables alone is a catenary, which has a most satisfying and pleasing appearance. The load of the roadway and trusses modifies this into a flat parabolic curve that is but little different in contour and appearance from a circular curve. Thus far and only so far, is it beyond power of human intelligence or strength of man made machinery to mar the beauty of a cable suspension bridge.

The types of suspension bridges are generally only two in number, one type having a loaded center span, with the backstays running direct to the anchorage, and the other with loaded backstays, which makes the structure one of three spans. The backstays in the first type may be carried much flatter than the angle formed by a tangent to the parabolic curve, and thus approximate the more pleasing appearance of loaded backstays, which naturally produces the most artistic bridge. Should the backstays when unloaded, be run to the anchorages at steeper angles than the tangent to the parabola, a most unpleasing result is produced, giving the impression that the cables are not properly anchored. When the unloaded backstays are termed straight, that is an incorrect statement, as they will always have a very slight curve from their own weight. "There is no power, however great, can stretch a string, however fine, into a horizontal line, which shall be absolutely straight." The sag of the cables has a very important bearing on the artistic appearance of a suspension bridge, as well as upon its economy and stiffness. Where the sag is one tenth of the span, the bridge is much

Clifton Suspension Bridge

Old Roebling Suspension Bridge Pittsburgh

stiffer sidewise than for a greater depth, and the appearance is the best. Except in rare cases the sag should not be made as small as one twelfth, nor deeper than one ninth, as with one eighth the bridge would be less stiff sidewise and give a poor artistic result.

The two basic types may be modified by trussing, when eye bar cables are used, which also form a part of the stiffening trusses. This was done in the trussing of the Point Suspension bridge at Pittsburgh, and contemplated for the backstays in an eye bar suspension design by Lindenthal for the Quebec bridge. The most pleasing manner of forming such trusses, is to fix the cables in a true parabolic curve, as was done for the Grand Avenue bridge in St. Louis. The Fidler Truss, invented by Professor T. Claxton Fidler, is one in which two sets of eye bar cables in the vertical plane, are trussed into the equilibrium curves for the half spans loaded, as was applied to one design made by the author, for the 1850 feet span of the Detroit River bridge. The resulting crossed cables have however quite pleasing curves, as they represent and suggest equilibrium to the eye of the observer.

The stiffening trusses which usually are merely suspended from the cables, are perhaps most pleasing when they are approximately straight, following the cambered curve of the roadway. The new stiffening trusses which were placed on the Cincinnati Suspension bridge some years ago, have an upward curve to the top chord, with a greater depth at the center of the span, and are not unpleasing in artistic appearance. Some designs have been made for three hinged stiffening trusses for the main span, with separate parabolic curves for each half span, but this produces a very unsatisfactory result artistically. When the backstays are not loaded and the roadway is carried up to the towers by lattice trusses of the viaduct approach, such trusses should match up in depth and elevation with the stiffening trusses of the center span.

The towers of a suspension bridge are its most prominent features and afford the greatest opportunity for artistic treatment, but are most always merely braced steel bents of unsightly appearance, without even the addition of finials to relieve their ugliness. When they are of stone they may and often have been made very monumental in appearance, as were

Roebling Brooklyn Bridge As Built

Original Design Brooklyn Bridge

the towers of the Roebling Brooklyn Bridge, although the attic stories as originally planned by Roebling and Hildebrandt were not built. The towers of the Fribourg bridge are quite monumental, even though they are mistakenly decorated with classic columns. The descriptions of suspension bridges in the following pages will attempt to point out the good and bad features of each structure, thus forming a basis for the judgment of the engineer in the making of future designs. The examples of real artistic design in steel towers are at the present very few in number, and none can be found that are truly works of engineering architecture. When an attempt has been made to have the engineering skeleton of the towers decorated, the attempt has nearly always been an outright failure, due to the decorator having an entire misunderstanding of the method of solving the problem to produce harmony and a truly artistic result.

The design of anchorages where they have been above ground, has been much more successful, and very often they are beautifully detailed masonry structures, with finely designed and beautiful parapets. The great bridges of recent design, have need for such massive anchorages, that it is best to have them mostly underground, or directly into rock if that is near the surface, so that all that is visible is some walls, which should have neatly designed corbel and coping courses. Where the anchorages are at the extreme ends of the bridge, they may serve as the foundations as well as for the ornamental entrances or the toll houses, which should be very carefully designed architecturally of such simplicity as to be in entire harmony with the structure, and not merely decorated with frivolous details or classic columns.

The most simple short span suspension bridges have been those in new countries, where wire ropes were used for the cables, and trees used for the towers or else timber bents were constructed to carry the cables. When longer spans were needed they were usually constructed in a very economical manner, with no idea whatever of being artistic. The earliest iron suspension bridge was the one over Menai Straits of 570 feet span, with iron eye bar cables. Thomas Telford the great English engineer and road builder, designed and built it just after 1819, and it is quite certain that no attempt was made to have it artistic in appearance, but the massive masonry

Menai Straits Bridge Telford

Tower Bridge Thames River London

towers and arched approaches were constructed to have a long life, and it is still in use after more than a hundred years. Could the towers have been designed with three tiers of arched openings, they would have approached the artistic, but all of the masonry was too heavy to harmonize with the light suspended span. The one similar, designed and built near the hoary Conway Castle, had battlemented towers to harmonize with the old Castle, and the rectangular towers of the later railway tubular bridge were of similar design, so here we have outstanding examples of bridges built to harmonize with the surroundings. The towers of the famous London Tower

FRIBOURG SUSPENSION BRIDGE

Bridge were constructed of mediaeval design to harmonize with the nearby Tower of London, and the stone towers of the Roebling Brooklyn Bridge harmonize well with the New York skyscrapers, although they were of much later construction.

The Clifton suspension bridge in England which was built in 1864, had stone towers of very massive construction with a two story arched opening for the roadway through each one, and openings in the sides. There was also an attic story on each one to cover the saddles, but the whole is an example of extreme simplicity which was not artistic. The Fribourg

Alaskan Primitive Bridge

Mill Creek Park Fowler

bridge in a very similar location, high up on the cliffs, was built in 1834, and had stone towers with arched openings for the roadway, with two classic columns on each side of each tower, and very well designed entablatures. They might be said to be the exception to the rule, not to apply classic details to make bridges appear artistic, as the Fribourg Towers are of so simple and chaste design, that they are more pleasing than most of the designs which have so far been made for any other suspension bridges. The stone towers of the Buda Pesht suspension bridge of 600 feet span, are of Romanesque design and very pleasing in appearance. The structure was built in 1845 by the noted English engineer, W. Tierney Clark, with eye bar cables, which pass through the towers below the entablature, which is most carefully detailed and surmounted by a well proportioned attic story, as was originally planned for the Brooklyn bridge towers. The starlings on the piers are of cut stone, and quite large to resist the heavy ice in the Danube, but they are very pleasing as part of a splendid design, and add much to a very satisfactory appearance of great solidity, which is also very real. The anchorage masonry and the entrances are quite beautifully detailed and will repay much study. The towers and entrances of the Invalides Bridge in Paris, and of the Aspern Bridge in Vienna are both very neatly detailed, and worthy of careful study.

The five span suspension bridge over the Dnieper at Kiev, built in 1853, has three main spans and four most chaste and artistic stone towers. There is a shaft on each side of the roadway, for each tower, connected by an arched portal. Each shaft has pilasters under the cables, and a neat dentiled cornice at the top. The masonry is formed into a solid pier below the roadway level, with icebreakers upstream. The Chelsea Bridge over the Thames in London, built in 1857, has somewhat too elaborate tower shafts, also connected by a portal over the roadway. They are surmounted by globe finials with spike above, and the whole is not unpleasing, but with greater simplicity in design, as is employed for the gate houses, a much more artistic ensemble would have resulted. The Hammersmith Bridge of over 400 feet span, has very similar towers which are too much ornamented, and also entrance pylons which are well proportioned, but likewise somewhat too gaudy in the details.

Hudson River 178th Street Bridge
O. H. Ammann Ch. Eng. L. S. Moisseiff Asst on Design

Williamsburg Bridge New York

The Kaiser Franz Bridge at Prague has towers of very chaste Romanesque design, similar to those of the Budapesht Bridge, but not so finely detailed. The Elizabeth Bridge at Budapesht is a quite modern design with eye bar cables, built by Czekelus in 1903, and is of 950 feet span. The towers are of steel with metal casing, and in general of much simplicity in design, with an arched portal and not too elaborate details. The gate houses are of beautiful design in cut stone, and the entire structure is one of the best pieces of suspension bridge architecture extant. The Rhine Bridge at Cologne, on the other hand, has towers of a somewhat bizarre design and certainly more like part of a Russian church in the shape and details. The bridge at Lyons over the Saône has piers to carry the towers, which are merely built in four steps, instead of having a regular batter. Each of the towers has two fine separate cut stone shafts with molded corbel course to carry the cap stone, which in turn supports the saddle. The saddle is covered by a semi-cylindrical cap, forming an extremely chaste tower, which is however very much marred in effect, by having only an iron latticed strut across, instead of an arched stone portal.

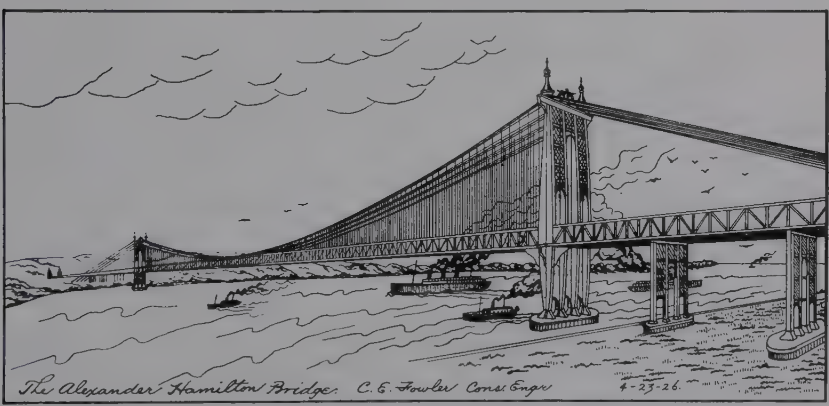

WILLIAMSBURG TOWER ERECTION FOWLER

The Roebling Brooklyn Bridge, as originally designed with an attic story or parapet on the towers, is the best design artistically, so far produced in America, as has already been stated. The great span of 1595.5 feet was for many years the

The Old Point Bridge Pittsburgh

Grand Avenue Bridge St. Louis

longest span in the world, very much surpassing the 1057 span built by Roebling at Cincinnati, which was completed in 1867, and is yet a very striking and monumental design, although the towers have no real artistic merit, being very much spoiled by the hemispherical caps over the saddles, which were added when the bridge was revised about thirty years after it was built, to replace even more homely ones of minaret design. The Williamsburg Bridge was the next great suspension span to be built, and it is with a few exceptions, the least a piece of bridge architecture so far to be created. The lattice towers could have been made very pleasing had they been carried straight up instead of being battered, and had some carefully designed finials crowned each shaft. The



NARROWS BRIDGE NEW YORK CITY FOWLER

stiffening trusses would have looked much better had they followed a vertical curve for the roadway, instead of a broken line. The designer just missed having a monumental bridge as well as a huge one, and no additional cost of any moment would have needed to be incurred for the artistic embellishments. The failure to complete the Roebling span towers and the failure to make an artistic bridge of the Williamsburg span, led to the later attempt to make the Manhattan bridge of 1470 feet span a work of architecture, and in many respects the result was pleasing. The graceful curve of the tower columns at the bottom is however essentially a structural feature, and had lattice bracing on both faces been substituted for the ordinary form of sway bracing as was used,

Cincinnati Suspension Bridge

Manhattan Suspension Bridge New York

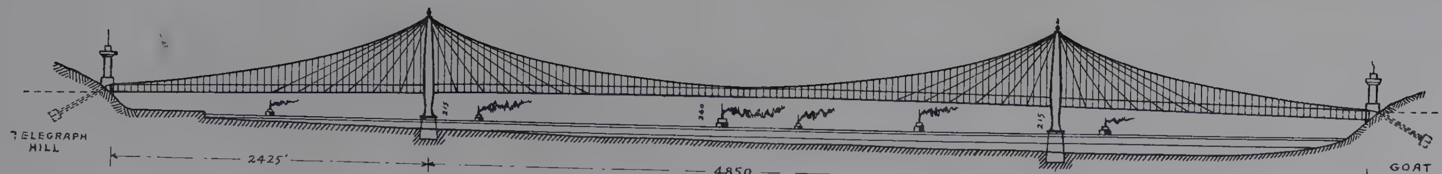
the towers themselves with more adequate finials, and their neat details, would have been a success architecturally. The detailing of the pier and anchorage masonry was quite carefully designed and executed. The entrances are well designed, especially at the Manhattan end, which is almost an extraneous piece of architecture, and very fine artistically.

The old Point Bridge at Pittsburgh, of 800 feet span, which was built by Hemberle in 1877, had a very unpleasing trussing of the eye bar cables for stiffening the main span, but the iron towers were quite well designed with latticed sides and quite appropriate capping and finials, although they were

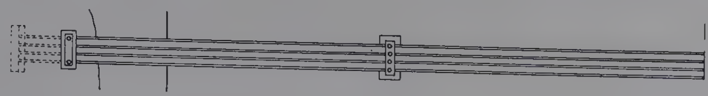
DETROIT BRIDGE ORIGINAL DESIGN FOWLER

somewhat too heavy in appearance. The Grand Avenue Bridge at St. Louis, Missouri, of 400 feet span, was built by Carl Gayler in 1890, and the parallel trussing of the cables is a very fine feature artistically. The towers are also of good design, but with inadequate finials. The new Hudson River suspension bridge of 3500 feet span, was designed by Ammann, whose original design of the towers 660 feet high was very neat and chaste in appearance, although one could wish that the stone casings about the steel work were not to be used, but that the structural work of the lofty towers had been designed of graceful outline at much less expense, and

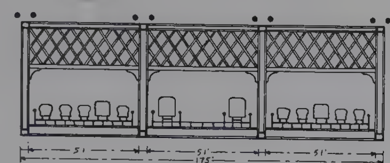
Hudson River Bridge Lindenthal



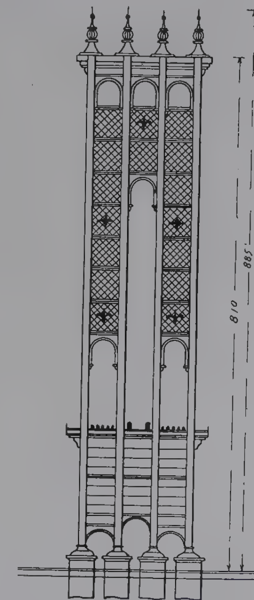
ELEVATION OF BRIDGE



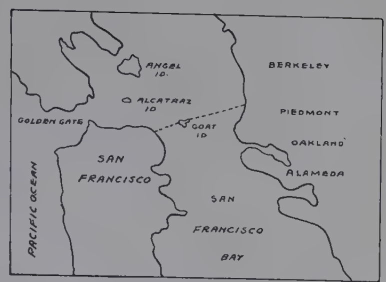
HALF PLAN OF BRIDGE



SECTION AT CENTER



MAIN TOWER



LOCATION MAP

EL CAMINO YERBA BUENA.

SAN FRANCISCO — OAKLAND BRIDGE

TELEGRAPH HILL VIA GOAT ISLAND TO OAKLAND

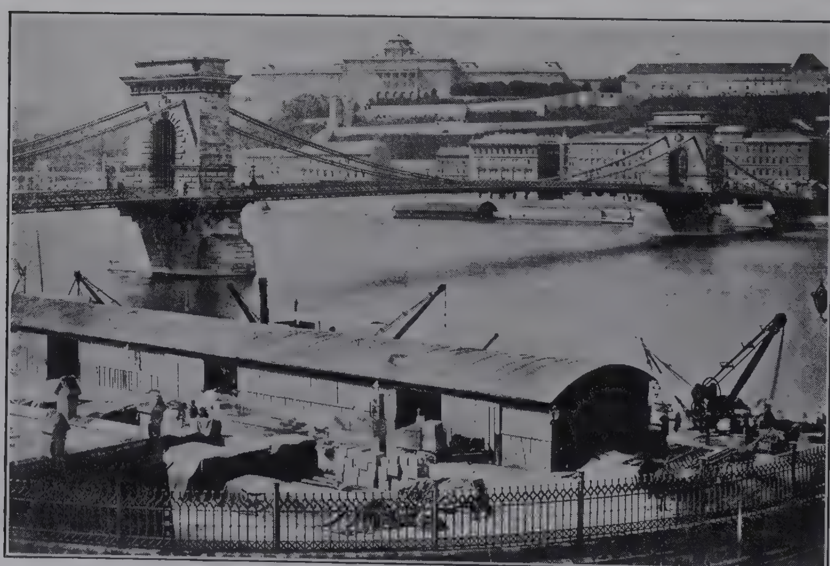
MAIN SPAN 4850 FEET SUSPENSION

CHARLES EVAN FOWLER, CONSULTING ENGINEER

25 CHURCH ST. NEW YORK CITY

FEBRUARY 26, 1926

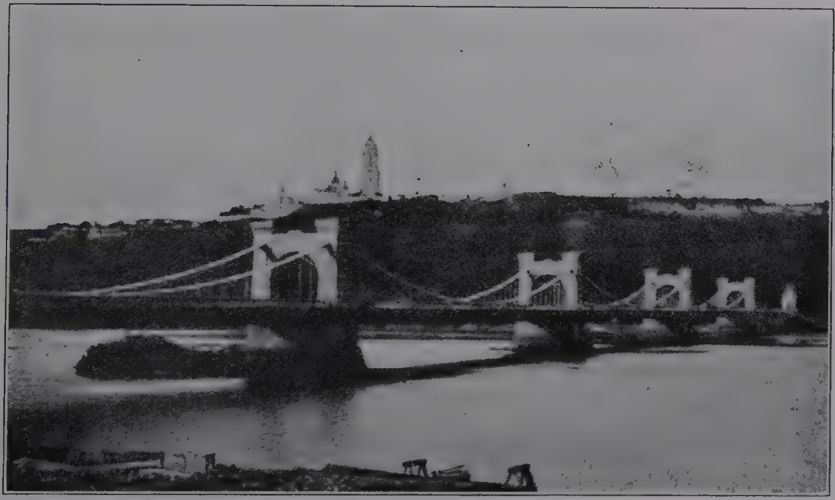
The Elizabeth Bridge Budapesht



Budapesht Suspension Bridge Clark

such wonders thus left to tell their own unhidden story of engineering skill and artistic beauty. The final design of the stone casings and stone approaches is of Romanesque motif, and made to harmonize with the rock masses of the Palisades, and of the masses of the buildings on the eastern shore.

The author's idea of suspension bridge design, especially for long spans, is that the towers which are the main features to receive architectural embellishment, should be entirely of steel with graceful outline, not having an undue amount of embellishment, but detailed without any of the usual unsightly features of purely utilitarian structural steelwork, and with



Bridge over the Dnieper at Kiev

adequate finials of proper proportion and chaste design. This was the basis for the original design of the towers for the Detroit-Windsor Bridge which the author designed in 1920. The three stories of triple arches for the portals over the roadway, is a quite usual feature of lofty cathedral design, and very appropriate for high bridge towers. Some very chaste details and proportions were adopted from classic architecture, and the finials as well as the crestings were planned in proportion to the height of the towers. The design could have been executed at no additional cost over the unsightly cross bracing which was substituted on the plea of economy.

Saone Bridge at Lyons

Chelsea Bridge London

SUSPENSION BRIDGES.

Location	Span	Side Sps.	Sag	Ratio	Twrs.	Width	Engineer
San Francisco	4850.0	2425	538	9.	885.	175.	Fowler
New York City	4550.0	none	500	9.	765.	210.	Fowler
New York City	3500.0	none	325	11.	650.	110.	Ammann
New York City	3240.0	1850	400	8.1	800.	120.	Lindenthal
Detroit River	1850.0	none	205	9.	355.	84.	Fowler
Detroit River	1850.0	925	205	9.	355.	84.	Fowler
Quebec, Can.	1800.0	659	270	6.6	400.	2T.	Lindenthal
Philadelphia	1750.0	720	200	9.	347.	125.	Bd. of Engrs.
Williamsburg	1600.0	none	178	9.	310.	118.	L. L. Buck
Brooklyn	1595.5	930	128	12.	Mas.	85.	Roebling
California	1500.0	750	167	9.	325.	40.	Fowler
Manhattan	1470.0	725	149	9.9	291.	120.	City N. Y.
Quebec, Can.	1300.0	500	160	8.	300.	2T.	Wentworth
Cincinnati, O.	1057.0	281	40	27.	Mas.	Hy.	Roebling
Niagara, N. Y.	1040.0	none	46	23.	Mas.	25.	Serrel
Wheeling, W. Va.	1010.0	none	46	22.	Mas.	28.	Ellett
Elizabeth, Br.	951.2	none	96	10.	137.	60.	Kubler
Fribourg, Sw.	870.0	none	65	13.	Mas.	22.	Schinkel
Niagara Ry.	821.0	none	50	16.4	60.	24.	Roebling
Point Br., Pitts.	800.0	none	100	8.	125.	34.	Hemberle
Rochester, Pa.	800.0	416	72	11.	steel	28.	Morse
E. Liverpool, O.	705.0	420	70	10.	106.	20.	Laub
Clifton, Eng.	702.0	none	70	10.	Mas.	31.	Brunel
Budapesht	685.0	297	50	14.	Mas.	46.	Clark
Morgant'n, W. Va.	608.0	none	50	12.2	60.	24.	Highway
Menai Straits	578.0	none	43	13.5	Mas.	Hy.	Telford
Cumberland	540.0	none	45	12.	80.	8.	Maryland
New River, W. Va.	510.0	none	54	9.5	60.	18.	Buchanan
Franz Joseph	492.0	156	54	9.	steel	31.	Austria
St. Louis, Mo.	400.0	150	50	8.	steel	60.	Gayler
Breslau	369.0	none	50	7.	Mas.	60.	Germany
Theiss River	351.0	170	50	7.	55.	48.	Hungary
Conway Castle	325.0	none	22	14.6	Mas.	Hy.	Telford

The design by the author of a 4850 span for San Francisco, goes much further towards what must be the ultimate in such design. Neat latticing has been used on both faces of the outer spaces of the tower columns, with arched openings over the roadway, but with the center one high up in the unbraced center space, all surmounted by three small arched openings at the top. The finials are in proper proportion for the great total height of 885 feet, and a design of great simplicity has been worked out, which has much merit as well artistically. The design by the author for the towers of a 4550 feet span for crossing the Narrows at New York City, is quite similar in general, but of Empire Style throughout, which is very appropriate for so monumental a structure, to form the eastern gateway to a continent, as would the San Francisco span form a western gateway. (see Ch. 14) The longest span for which the author has made calculations and estimates was 5280 feet or one mile clear span between the towers, and this was only a test design. However, these tests have conclusively shown that such very long spans are possible, and that they are proportionately cheaper than shorter spans of the suspension type. The special wire developed by the author for Detroit, and the investigations of the reduction of stiffening trusses due to inertia in long spans, as well as other advances, have made such long spans economically possible, but they require the most careful artistic treatment.

CHAPTER VII.

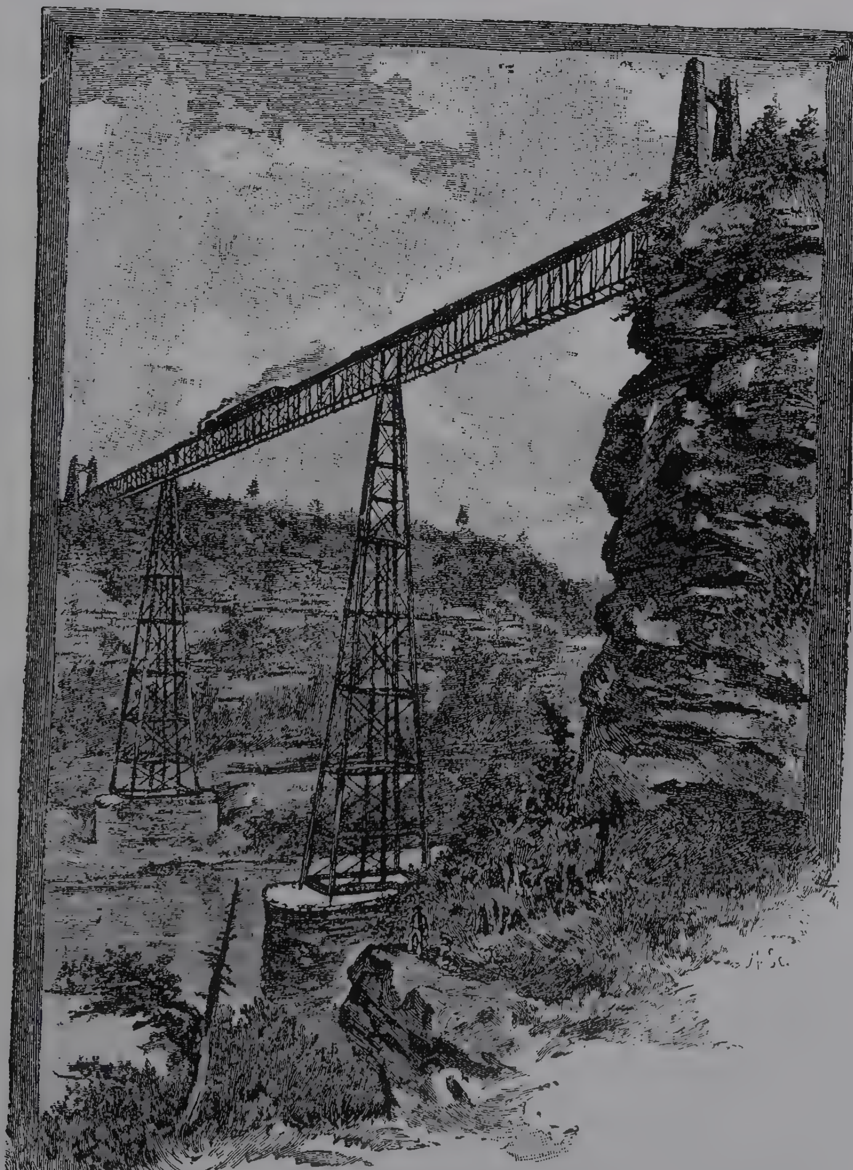
DESIGN OF CANTILEVERS AND CONTINUOUS BRIDGES.

The design of cantilevers and continuous bridges may well be considered together, as the cantilever is merely a form of the continuous girder, in which the points of contraflexure are fixed by hinges or pins. The cantilever may have anchor or shore arms, from which cantilevers extend over piers to

Old Niagara River Cantilever

support a suspended span, as was done in the case of the old Niagara Cantilever, or it may have anchor spans for carrying cantilevers at either end, as was done in the case of the author's Knoxville bridge, which also had anchor arms on either shore, thus making five main spans, or three with cantilever arms and suspended spans, and two anchor spans. The resultant effect was five arched spans, in which the

Charles Shaler Smith



Kentucky High Bridge Shaler Smith

Britannia Bridge Wales

Lachine Rapids Bridge Shaler Smith

anchor spans were made shallower than was economical, and with greater deflections than they would have had if made deeper, but which would have sacrificed the architectural appearance of the bridge. The White Pass Arch was erected as a cantilever, by using the side spans as anchor arms, and when the center pin of the arch was driven, the bottom member of the side span next to the skew back, was fastened with bolts in slotted holes, so that these two side spans acted finally as simple trusses. In this case beauty was sacrificed to utility.

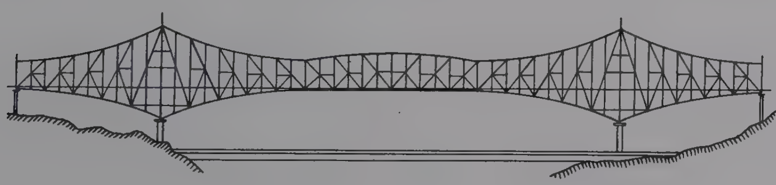
The continuous girder is somewhat more economical than the cantilever bridge, but should not be used unless the foundations are upon rock or practically unyielding material, as

SCIOTOVILLE BRIDGE LINDENTHAL

anything more than a slight settlement might disarrange the stresses. Even when on a solid foundation some engineers prefer fixing the points of contraflexure, as was done in the Kentucky High Bridge, built by C. Shaler Smith, the dean of American bridge engineers. This bridge on account of its height of 275 feet above the bottom of the gorge, was a very spectacular structure, but like the White Pass Arch, it depended upon the impressive scenery for its artistic urge, and not upon any inherent beauty. The Lachine Bridge, built over the St. Lawrence river by the same engineer, was a continuous girder of four spans, in which the shore spans were deck trusses, and the two middle spans were through trusses. The connection was made between the deck and through

Robert Stephenson

spans by curved chords, which to the author presented not only a striking, but also a graceful, artistic, and pleasing effect. Such structures should be preserved, but this was replaced some years ago by much heavier modern simple truss spans. The Sciotoville Bridge over the Ohio River, built recently by Lindenthal, has two continuous spans of 775 feet, and as required by theory the trusses are much deeper over the center pier. It is of very pleasing appearance, on account of its symmetry, but could have been made quite artistic by using curves instead of broken lines for the line of the top chord of the trusses, and thus have been almost as pleasing as the original Lachine bridge. The masonry of this bridge is neat but of the plainest kind of concrete piers, whereas so expensive a bridge might well have had granite piers or at least ones with stone facing, and with molded corbel courses



THE FIRST QUEBEC CANTILEVER

and copings of cut stone, to give a more artistic appearance. The use of finely detailed engineering masonry is not common in the United States, as usually it is more or less hidden, and is regarded as a purely utilitarian feature. The bridges of Europe usually have quite fine masonry piers, abutments, and entrances, of very careful detailing, which is very much a feature of the structure, adding much to its character and artistic ensemble.

The first Quebec bridge of 1800 feet span had curved chords, so that the structure would have been a very pleasing and artistic one, but when it failed, the outline was changed to one of straight lines, and thus the greatest cantilever span in the world is to say the least, not a thing of beauty, and is entirely devoid of artistic features. That it could have been made much more pleasing in appearance is demonstrated by the illustration, where suggested finials on the towers and

Quebec Cantilever Bridge

Quebec Bridge with Pylons and Finials

pylons at the ends have been drawn on the picture. The great Forth bridge across the Firth of Forth, Scotland, with its two great main spans of 1710 feet each, was opened in 1888, having been designed and built under Sir John Fowler and Sir Benjamin Baker as engineers. The curve of the bottom chords of each span is a very graceful ellipse, but there all attempt at beauty ends, as the straight lines of the top chords of the cantilevers offset any other points in the trusses which

QUEENSBORO BRIDGE NEW YORK

are in the least artistic. The masonry of the piers and approaches is however, worthy of study. The bridge has been likened to two huge elephants standing in the waters of the Firth of Forth. The author's design for three 2000 feet spans for San Francisco Bay from Telegraph Hill to Goat Island, attempted to present an outline somewhat more pleasing in effect. The fact that there are three spans instead of two, as in the Forth Bridge, makes it fundamentally much more artistic, the elliptical curves of the bottom chords of the main spans are carefully drawn to harmonize with their greater

Cincinnati-Newport Bridge

The Pecos Viaduct Texas

length, as well as other parts of the structure, and the parabolic curves of the top chords are much more pleasing than the straight lines of the Forth Bridge. The addition of fifty feet high finials on each tower post removes the gauche appearance, and the finish thus given to the design is accentuated by the entrance arches or towers at each end of the structure. The aesthetic features of such a huge structure are quite difficult to plan, as the very size makes it impossible for the beholder to see it all in one view, so that the best that can probably be done is to have each component part as grace-

English Channel Bridge as Proposed

fully and as artistically designed as possible, thus giving a general impression of beauty from each point of view.

The usual type of cantilever bridges of small span has been very much like the old Niagara Cantilever, and the cantilever span of the Pecos Viaduct, but one of the first in which graceful curves were used, was in Osborn's design of the Cincinnati-Newport bridge, which was quite pleasing and somewhat artistic. Since that time many cantilevers of similar length of span have been built, and most of them have been so nearly servile copies of such an outline, that one is surfeited by seeing what may now be termed standard cantilever bridges almost everywhere. The author in some recent designs has sought to break away from this by using curved top chord anchor arms, carrying a through cantilever arch center

Franz Joseph Bridge Budapesht

Forth Bridge Scotland Fowler and Baker

span, and the result seems to be much more pleasing and monumental in appearance than the ordinary types. The designer must always seek if possible to break away from tradition, if a real engineering architecture is to be achieved, and to attempt to design each structure as an individual work of art, but if this is not possible, to make bridges and other engineering works at least of pleasing outline and detail. All that can be accomplished at present along artistic lines is to endeavor in each structure to do something better than has been done in the past, believing that in a few years engineers will become more appreciative of the fundamentals of engineering architecture and seek to formulate a more complete system

CZERNAVODA BRIDGE ROUMANIA

for each class of work than can be done at the present time, with the entire scheme depending upon a somewhat slow evolutionary process.

The Queensboro bridge over the East River at New York City is one of the world's most notable cantilever bridges, and without any suspended spans, the curves of the cantilever arms should have been smooth continuous ones, harmonizing fully with the anchor span curves. The attempt to add to the artistic appearance of the bridge by crestings and finials on the towers, was somewhat of a failure, as they are of too frivolous a type to harmonize with the dignity of a great bridge. The finials are much too attenuated for their seemingly too great height, and should have been designed to be fully in

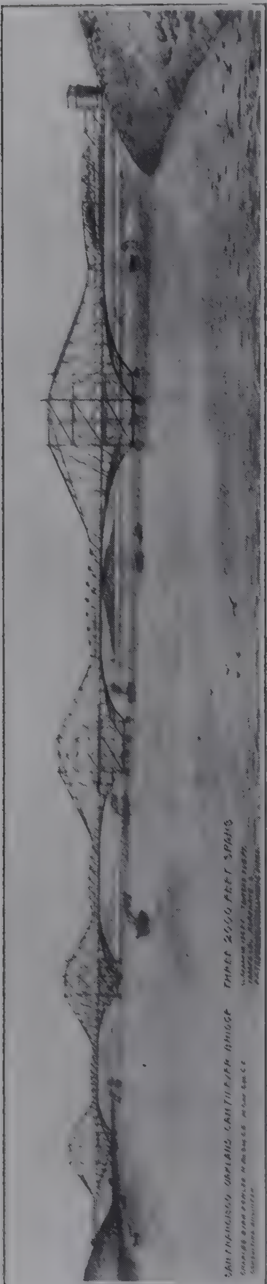
Hassfurt Cantilever over the Main

Elbe Canal Bridge

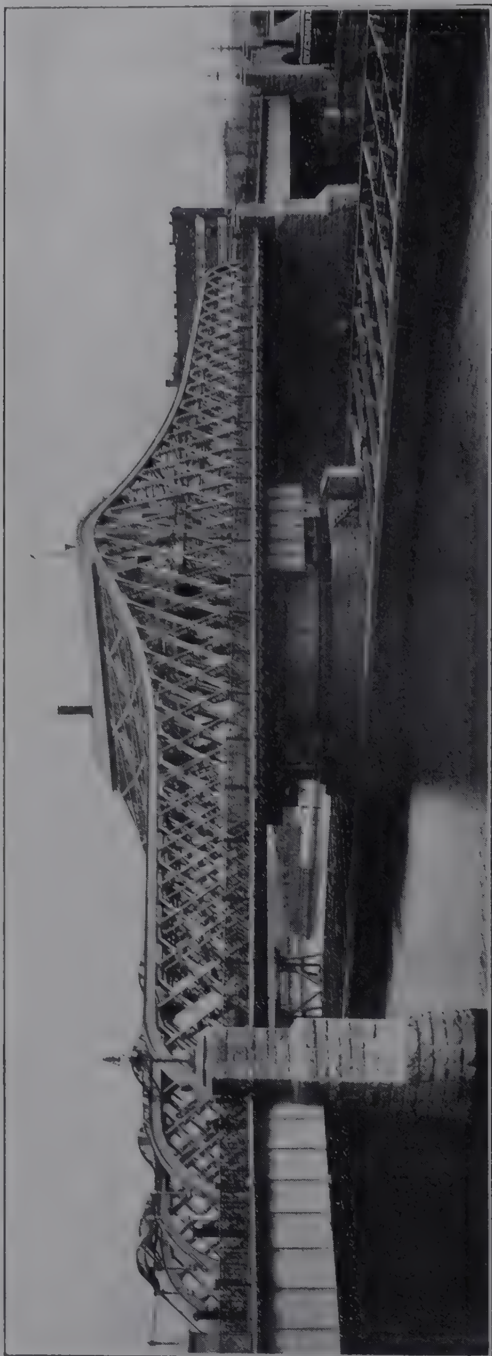
harmony and proportion to the structure they seek to ornament. The bridges of New York City have in general the highest class of masonry of any in the world, that of the Queensboro bridge being especially notable, and will be described later on in another chapter.

The bridge that was proposed some years ago for a crossing of the English Channel, over twenty-one miles in length, was designed by Schneider and Hersent the French engineers, with Sir John Fowler and Sir Benjamin Baker as the English consultants. The anchor spans were about 1640 feet in length, and the alternate spans composed of two cantilevers and suspended span were about 1310 feet in length. The sweeping curves of the lines of the top chords over the entire length of the anchor arms and cantilevers, were very graceful and pleasing, and about all that could have been done to make such a long structure pleasing and artistic. Had towers of appropriate design been introduced every seventh span, of artistic and harmonious design, it would have broken the monotony and have made of it a nearer approach to a work of architecture. The great Czernavoda bridge over the Danube in Roumania is the most striking cantilever bridge so far constructed, and was built in 1895 from the plans of the engineer Saligny. There are four spans of 623 feet and one of 460 feet, two of the five being anchor spans and three of them cantilever spans. The three suspended spans have curved top chords, while the concave curves of the anchor spans and cantilever arms meet at a point above the common pier, making a most striking and quite pleasing outline. The high piers of stone have rounded ends, and the two ends of the bridge have most monumental towers with arched openings over the deck of the bridge. The finely molded cornice is supported by beautifully detailed dentils, while the whole is surmounted by a carefully detailed parapet. The entire structure must be classed as an outstanding work of engineering architecture, with numerous features worthy of emulation.

The Franz Joseph bridge over the Danube at Budapesht, was built in 1896, and has graceful lines that suggest a suspension bridge rather than a cantilever. The metal towers are an improvement over those of the Queensboro Bridge, but somewhat too ornate in detail. The gate houses are quite



THE SAN FRANCISCO-OAKLAND CANTILEVER DESIGN FOWLER



DRAWBRIDGE OVER THE HARLEM NEW YORK

neatly detailed, but not nearly so pleasing as those of the other bridges nearby. The small traffic bridge over the Elbe Canal has a pleasing outline, with an ellipse for the main span and a half ellipse for the anchor arms. The traffic bridge over the Main at Hassfurt by Gerber, built in 1867, shows how on the other hand, the use of theoretical outlines will serve to make a structure grotesque, as it looks like three small dirigibles placed end to end, after the manner of a string of frankfurters. The designer need not adhere too closely to a theoretical outline to obtain the greatest economy, as a

HARLEM RIVER DRAW NEW YORK

variation of enough to make the outline pleasing will at most add only a small per cent to the weight and cost, and usually the better outline will reduce the fabricating cost.

The revolving draw bridge is a type of continuous girder, and lends itself to some very pleasing outlines, although the chance for variation is not wide, and one soon tires of so many draw bridges with the concave curves sweeping up to the tower at the center. The tower may be strikingly treated by carrying well designed finials on the posts, and perhaps even some modest crestings, although they usually detract from a monumental appearance, which is desirable for city draw bridges in particular.

The two city draw bridges of riveted construction designed and built by the author at Raymond, Washington, are of the

Willapa Harbor Drawbridge Fowler

Raymond Washington Tilted Draw Fowler

CANTILEVERS AND CONTINUOUS GIRDERS

Location	Span	Type	Anchor	Depth	Width	Remarks
San Francisco	2300	Canti.	900	475.	4T.	Fowler
San Francisco	2000	Canti.	650	450.	4T.	Fowler
Quebec, Can.	1800	Canti.	500	318.	2T.	Cooper
Quebec, Can.	1800	Canti.	515	310.	2T.	Johnson & Porter
Forth, Scot.	1710	Canti.	680	361.	2T.	Fowler & Baker
English Channel	1640	Canti.	1310	230.	2T.	Schneider & Hersent
Queensboro, N. Y.	1182	Canti.	459	185.	86.	Lindenthal
Sukkur, India	820	Canti.	130	140.	1T.	Rendel
Monongahela	812	Canti.	346	126.	2T.	Boller
Memphis	790	Canti.	621	78.	1T.	Morison
Sciotoville, O.	775	Cont.	775	129.	2T.	Lindenthal
Beaver, Pa.	769	Canti.	320	120.	2T.	Lucius
Sewickley	750	Canti.	300	115.	Hy.	Buel
Mingo Jct., O.	700	Canti.	298	109.	2T.	Boller
Thebes, Ill.	671	Canti.	521	75.	2T.	Noble
Steubenville	660	Canti.	230	110.	1T.	Ohio River
Red Rock	660	Canti.	165	75.	2T.	Santa Fe Ry.
Marietta, O.	650	Canti.	600	90.	Hy.	Strobel
Czernavoda	623	Canti.	467	105.	1T.	Roumania
Poughkeepsie	548	Canti.	525	80.	2T.	Schneider
Allegheny River	520	Cont.	350	75.	2T.	P. B. & L. E.
Cincinnati	520	Canti.	252	40.	38.	Osborn
Cincinnati	516	Cont.	300	50.	2T.	Sou. Railway
Burlington	480	Canti.	260	60.	Hy.	Iowa
Niagara, N. Y.	470	Canti.	178	56.	2T.	Schneider
Britannia	460	Cont.	230	30.	2T.	Stephenson
Ruhrort, Ger.	443	Canti.	418	82.	30.	Rhine Riv.
Cornwall, Ont.	420	Canti.	210	60.	1T.	Canada
Lachine	408	Cont.	268	40.	2T.	Shaler Smith
Nelson Riv.	400	Cont.	300	50.	1T.	Canada
Kentucky	375	Cont.	375	37.5	1T.	Shaler Smith
Knoxville	242	Canti.	242	50.	42.	Fowler
White Pass	240	Can. Er.	80	90.	1T.	Fowler

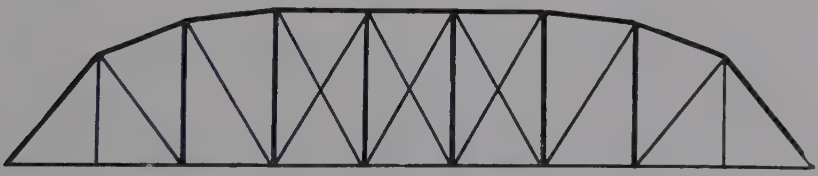
usual type with curved top chords, and while neat in appearance, it is to be regretted that money was not available for some chaste ornamentation. The value of the riveted trusses was demonstrated when one of the spans was tipped up at an angle of 30 degrees when struck by a passing steam ship, and was jacked into place again with practically no repairs being necessary. The two Harlem river draw bridges illustrated, show both the ornamentation for the tower as mentioned on one bridge, and rather pleasing smooth reverse curves for the other one, which is also a close riveted lattice structure.

The use of entrance arches or towers at the ends of the span, often adds much to the pleasing appearance of a draw bridge, and all the masonry should be carefully designed and neatly detailed, as it is much more exposed to observation than in the case of fixed spans. Some long swing spans of about 500 feet total length, have had the ends curved into a near segment of an ellipse for economy, and it results in a quite pleasing effect artistically. The bascule spans which dot the landscape for crossings of navigable waters, are most of them very unsightly, but of recent years an attempt has been made to render them more pleasing, by hiding the hideous counterweights in entrance towers or else below the roadway level. The outline of the top chord of a double leaf bascule bridge can be made into a curve to resemble a suspension bridge and if the abutment towers or operating houses are of proper proportions, the result is not unpleasing. The vertical lift bridge is yet to be built that will be a sightly object, and the field is open for some designers to reduce them to artistic creations, as well as works of utility.

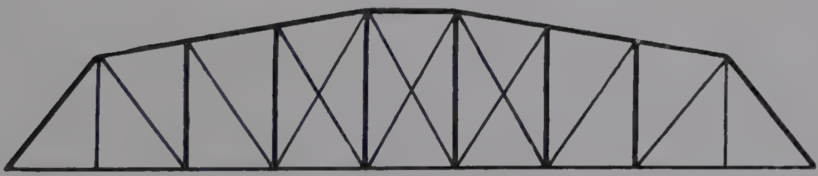
CHAPTER VIII.

DESIGN OF TRUSS BRIDGES AND VIADUCTS.

The design of truss bridges and viaducts to create works of engineering architecture is one of the most difficult problems confronting the engineer. When there is more than one span in a bridge structure it is best to adhere to one of three, five, or seven spans as the first fundamental of artistic design, and to plan a viaduct with the spans in groups of three, five or seven.



ELLIPTICAL TRUSS



CAMELBACK TRUSS

The first bridge designed and built by the author was in 1887, and it was a two span Howe Truss railway bridge for the Hocking Valley railway, being the heaviest one of the type to be built up to that time, to carry 2-92.3 T. locomotives. The lacy appearance of the spans in such a beautiful setting somewhat belies the principles herein set forth.

The outline of modern through trusses may be made more artistic by approximating the parabolic curve of moments, which will usually be either an arc of a circle for the line of the top chord; or to have the panel points from end to end of the span, including the batter posts and top chord, lie in an

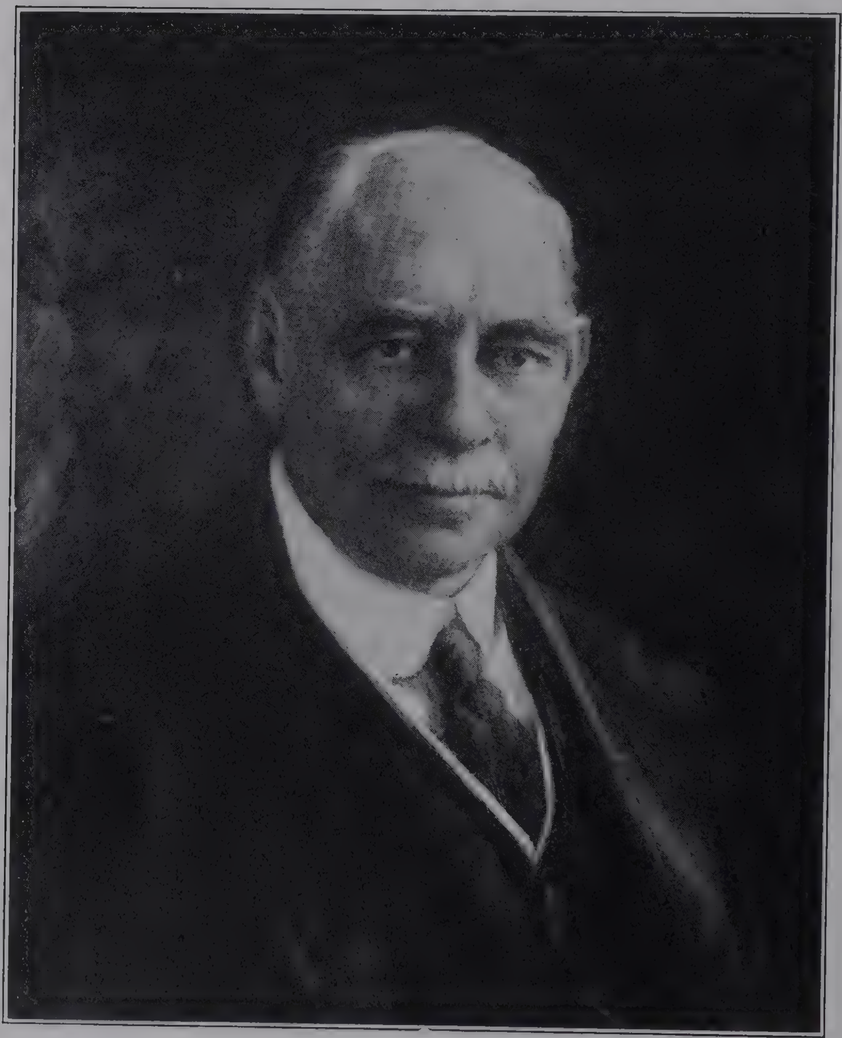
Old Fink Bridge Louisville

New Louisville Bridge P. R. R.

elliptical curve. The form often employed for such spans, with a broken line for the top chord, is called a "camel back," and is very unsightly. Many European and some American designs have the end posts vertical, with an arc of a circle for the line of the top chord over the whole span length, which is in some respects satisfying artistically, but not conducive to real architecture. When the spans are of the deck type, the bow string outline is sometimes used, with a full parabola from end to end, as was done for the approach spans at either end of the Upper arch at Niagara, and for some of the spans

Hocking Valley Howe Truss Fowler 1887

in the approaches to Hell Gate Arch, but this is far from pleasing to the eyes of most observers, as the spans appear too attenuated at the ends. Where the chords of the spans are parallel, the only architectural features usually possible are ornamental entrance arches and gate houses, as are so often used in European designs. The spans of viaducts are often quite lacy in appearance, when they are of lattice construction, but the only truly artistic ones are those with pleasing outlines for the spans, such as the arches employed in the Riverside Drive viaduct in New York City at 125th Street.



George Herndon Pegram

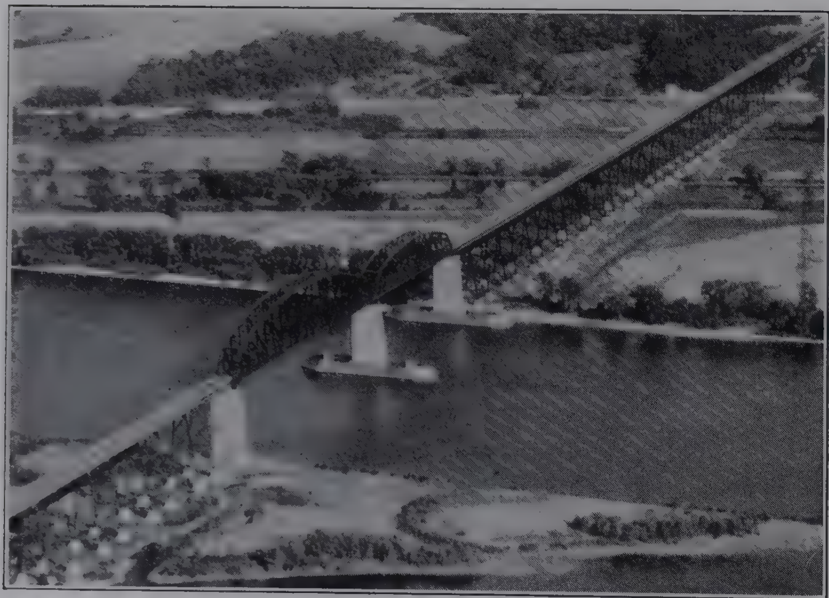
The portals and cross bracing in through truss spans may be made pleasing and artistic by using arched forms, or by solid plate webs perforated in artistic designs. The cross bracing in viaducts can also be of arched types, or else curved brackets used for a finish and to reduce the bending stresses due to transverse forces acting upon the structure. Curved brackets are frequently used for similar purposes in truss spans. The web members of trusses are usually not artistic features of a bridge, but are not unpleasing in close lattice work, especially where curved out gussets are employed. The

Scioto River Chillicothe Ohio Fowler

type of trusses without diagonal members is being employed to some extent, and while such structures may be made quite pleasing, they are very unsatisfying to the trained observer. Such a criticism does not apply to arch design, where the absence of diagonals is the rule, except in spandrel braced arches.

The bridge designed by the author for Chillicothe, Ohio, is an example of a bridge with perforated portal and cross bracing struts, which is much in harmony with the dignified character of the design, and the Spring Common Bridge is another one where the roadway is forty feet in width, with

New Lachine Bridge Fairbairn-Motley



Castleton Bridge N. Y. Central Ry. Welty

the same ornamental perforating of the deep girder bracing and the large curved brackets. There was also used on this structure a very chaste design of cresting with finials of classic proportions, and a harmonious design of handrail, with severely classic newel posts. The top chord of the first is of curved outline, while the latter has parallel chords. The bridges at Castle Rock and Bellingham, Washington, have nearly elliptical outlines, but could have been made more artistic by using a full elliptical outline as shown in the line drawing. The old Louisville bridge, designed by Albert Fink,

SPRING COMMON YOUNGSTOWN FOWLER

had a 400 feet subdivided Warren truss with parallel chords, which represents the type of most early American bridges of long span, and the abrupt change from this long span to the Fink deck spans was not pleasing, and the better outline of the old Lachine continuous bridge should be compared with it, to study the more pleasing arrangement. The new Louisville bridge has a long span with curved top chord and is of a much more artistic character, although its purely utilitarian purpose is not to any extent hidden.

Dirschau Bridge over the Weichsel

Weichsel Bridge Germany

The huge through spans of the new Lachine Bridge are much of the same type as the new Louisville span, but not nearly so pleasing as the old Shaler Smith design. The new Castleton Bridge of the New York Central Lines over the Hudson River just below Albany, has two through trusses of similar outline to the new Lachine Bridge, but less pleasing owing to the fact that one span is so much shorter than the other, and consequently so very much dwarfed in appearance as to spoil any possible harmony. The three spans of the Merchants Bridge at St. Louis, over the Mississippi, are a most striking illustration of the fundamental need being met by an odd number of openings, if a design is to have any real artistic merit, and the pleasing result artistically is much en-

MARIENBURG BRIDGE OVER THE NOGAT

hanced by the curved outline of the top chords of the trusses. The one truss bridge in the United States which conforms quite fully to European practice, is the Lindenthal Pauli Truss design at Smithfield Street in Pittsburgh. The curved top and bottom chords of this type of truss are more frequently seen in Europe, as is the somewhat monumental type of portals, which add much to the character of the design, although not of the really imposing type of masonry portals which will be described. Most of such portals may be classed generally as mediaeval in design, so while many of them have decorations of fine design and detail, the ensemble is too often heavy in appearance, or even so bizarre as to be unpleasing and not in harmony with the structure, nor even with the sur-

Elbe Bridge at Lauenburg

Cologne Bridge over the Rhine

roundings. Where the surrounding buildings are of the mediaeval period, such designs are not incongruous, but unless the towers are of real simplicity, it is usually better to omit such entrances.

The Marienburg bridge over the Nogat has battlemented towers with rounded ends and a large segmental arch over the double track railway, with four small gothic arches above, carried on columns. The design would have been much more artistic if three small arches had been used, instead of the four. The gate houses are small and of extremely plain de-

RUDOLF BRIDGE AT VIENNA

sign, with battlemented tops. The whole may be classed as a relatively good mediaeval design. The Britannia Bridge built by Robert Stephenson over Menai Straits from 1842 to 1846, was fundamentally difficult to design artistically, as there are only four spans, two of 460 feet and two of 230 feet, and these are straight rectangular tubes with no elements of beauty. One must however admire the manner in which such a problem was met by strict adherence to a straight line design, and in accentuating the nearly perfect symmetrical character of the structure. The hugh lions at the entrances are very appropriate for such a monumental bridge, with its huge square towers at each end, and with the piers carried up into towers with flat tops, and rectangu-

Old Kehler Rhine Bridge

Nymwegen Bridge Holland

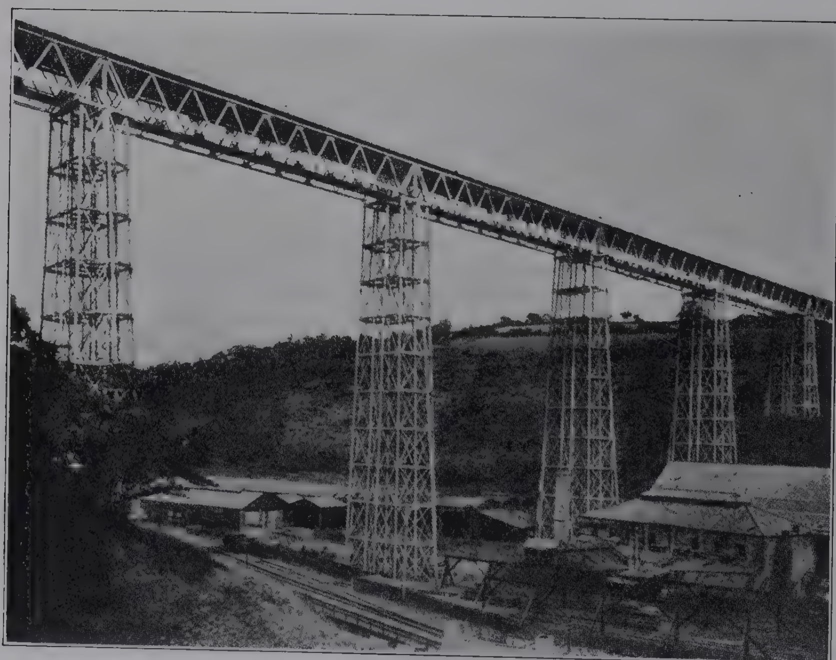
lar openings, so that it may be considered as an outstanding example of simplicity, symmetry, harmony, and proportion for a very noted piece of engineering architecture.

The Dirschau bridge over the Weichsel completed in 1857, is another rectangular design where the end towers are two separate shafts with a gothic arched portal between, all battlemented and finely detailed. The historical bas-relief on each portal adds much to the character and variety of the design, as do the round towers with battlemented tops on

CASTLE ROCK WASHINGTON FOWLER

each end of each pier. The Rhine Bridge at Cologne, built by Lohse in 1859, is a rectangular, flat topped lattice truss bridge, with tall towers of two battlemented shafts, joined below by a double arched portal which carries an equestrian statue. The openings in the towers are very finely detailed, as are the tops of the shafts with their beautifully dentiled cornice. The Saltash Bridge built by Brunel in 1859, is a very famous structure of two spans of Pauli trusses, for which the lofty and slender masonry piers have been carried up above the roadway level, without proper finish or cornice. The tall bifurcated piers of the approaches add to the slender appear-

THE SALTASH BRIDGE ENGLAND



THE CRUMLIN VIADUCT ENGLAND

ance of the entire structure, and assist in proclaiming it as merely a work of utility. The new bridge over the Weichsel is a five span Pauli truss bridge, with imposing portals of mediaeval design, with a gothic arch over the tracks, but the decorations give it a quite bizarre effect as compared with the one at Dirschau already described, but it is a more monumental appearing bridge than the old Kehler bridge over the Rhine, built in 1860. This bridge has gothic portals, which would be more appropriate as part of the facade of a cathedral, and while somewhat imposing after a fashion, their only

Northern Pacific Ry. Viaduct Fowler

redeeming feature is that they are somewhat in harmony with the three lattice spans of the structure.

The three main spans of the railway bridge over the Waal at Nymwegen, built by Van den Bergh in 1880, represent the type already referred to, where the end posts are vertical and the top chords arcs of circles. With gate houses as shown at the shore, the spans have a fairly pleasing appearance, which would have been enhanced if a tower to harmonize with the gate houses had been constructed on the river pier at the end of the three long spans. The bridge over the Elbe at Lauenburg is of the same type of spans, with too slender isolated shafts on each end pier, which in themselves are not of

Java Railway Viaduct

Twenty-first St. Portland Fowler Constr.

bad design, except perhaps they appear slightly top heavy. Thus it will be seen from the foregoing criticisms, that it is a somewhat more difficult problem to design stone portals to harmonize with a truss bridge, than for an arch or some other types. When the complete design has been made, the engineer should give the ensemble much consideration, in an effort to eliminate any bad features of the design, and to make sure that each and every thing harmonizes with other features of the bridge and with the environments.

The design of viaducts, especially in America, has seldom received much consideration from the artistic standpoint, and nearly always they remind one of the old timber trestle perpetuated in steel. The one built by the author on the Northern Pacific Railway in Washington was nearly 1000 feet long, 110 feet high, and contained over a million board feet of fir timber. Such structures while having a lacy appearance and being somewhat imposing, were of course only temporary, and have nearly all long since been replaced with steel. The Pecos River viaduct on the Southern Pacific Railway is one of the tallest and most daring bridge structures in the world, with the cantilever span over the river already mentioned, but it was originally built in steel. There is nothing artistic in such a structure, nor little chance for architectural treatment except at a very considerable extra cost for great semi-circular arches or some special design. The Riverside Drive viaduct in New York City is of a very artistic character with arched spans, which are quite satisfactory architecturally, and such spans were necessary not only for appearance in the midst of a great city, but also for the clearance required. The famous Crumlin Viaduct in England is of somewhat monumental appearance with its tall towers and quite long lattice spans, but when the lines are all straight, it is much more pleasing and artistic to use a design similar to one in Java over the Tjitondoei, where the lattice towers and the close lattice work of the spans harmonize so well with the lacy palms in the landscape. This kind of a design is in violent and pleasing contrast with the plate girder viaducts which are so numerous in America, and the design of future viaducts and of great bridges with simple truss spans, offers a splendid

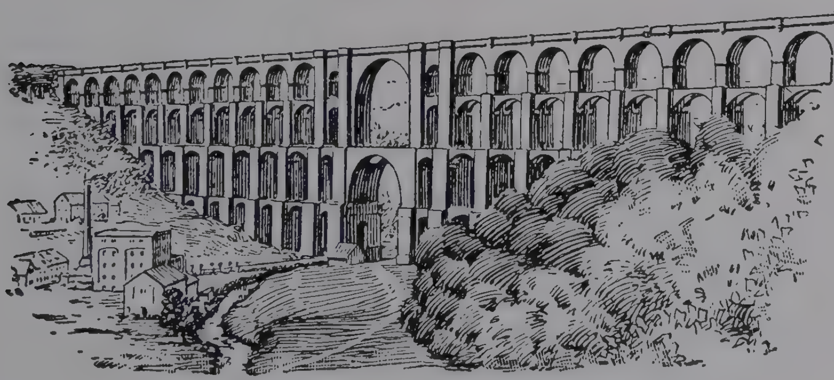
Riverside Drive Viaduct New York

Duluth Double Track Viaduct Fowler

opportunity for the future devotee of engineering architecture, to create structures which are not only utilitarian, but which are also artistic.

The stone viaduct over the White Elster river in Goltsch, Saxony, is one of the most imposing bridge structures in the world. The great two story arch over the river is flanked by four story arched approaches, with each story stepping in from the one below. The entire design is of the greatest simplicity, but comprising as it does a harmony in design and with the surroundings, it is a splendid piece of engineering architecture.

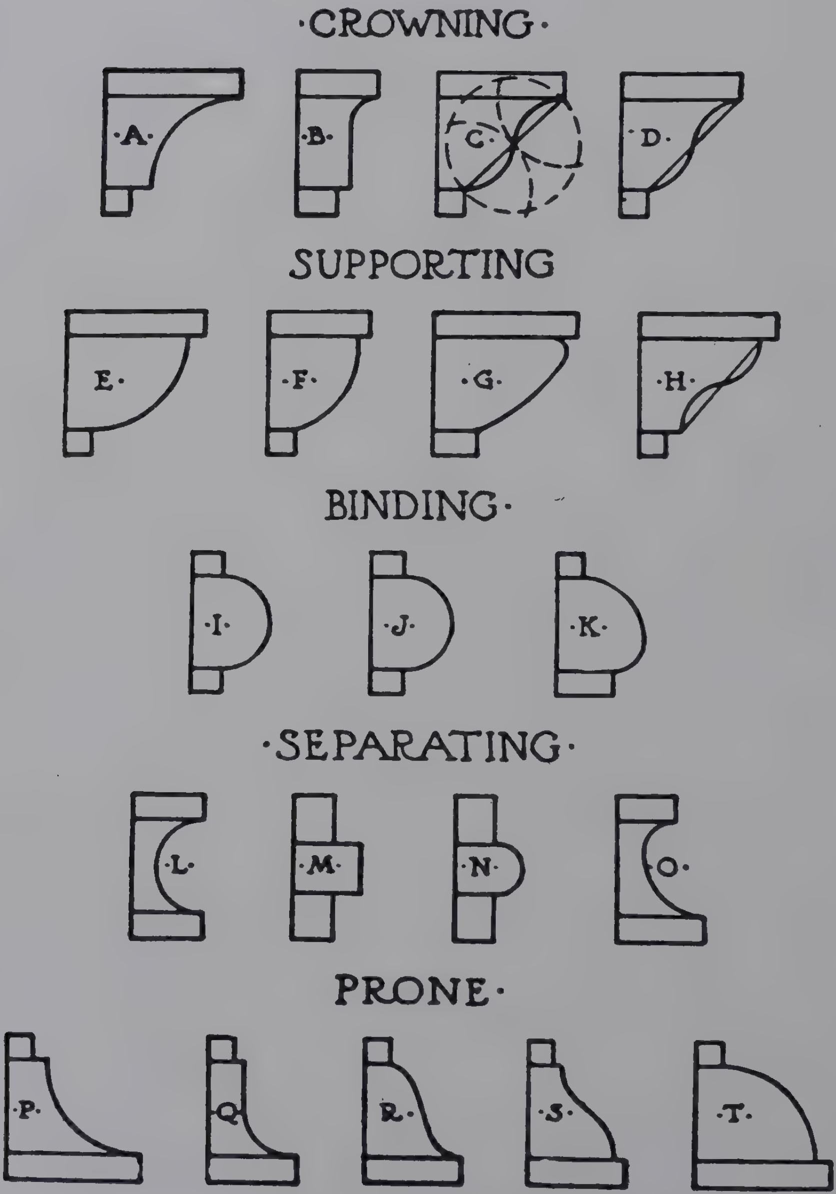
The double track steel railway viaduct at Duluth, Minnesota, designed by the author represents the prevailing type



VIADUCT OVER WHITE ELSTER SAXONY

of such structures. The length of 2500 feet was made up of plate girder spans of varying lengths to suit the street crossings, and intermediate spaces across the blocks, with the longest span of 86 feet being a crossing of another railway. The most that can be said as to its appearance, is that the solid and heavy character is not unpleasing.

The Twenty-first viaduct over the Sullivan Gulch at Portland, Oregon, built by the author, was 75 feet in height, to carry the full width of the street. It is of the highest type of construction, but being of rectangular design similar to the steel viaduct just described, it is only neat in appearance, and is entirely lacking in that beauty which one beholds in a structure like the one over the White Elster river.



MOLDINGS FOR MASONRY

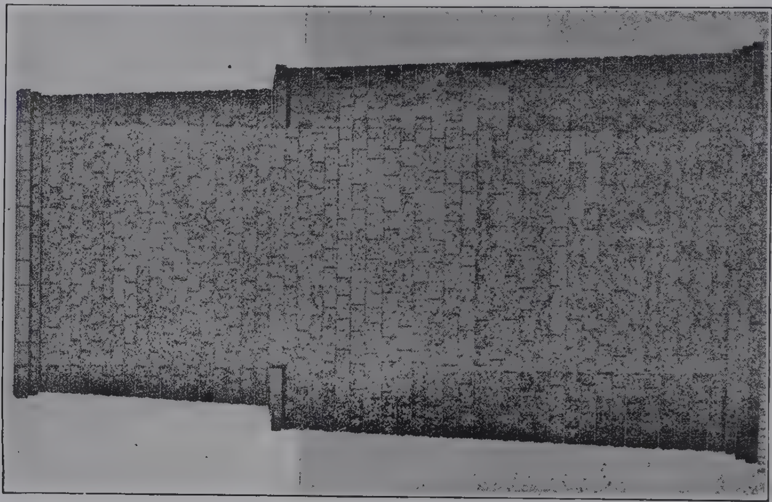
A—Cavetto
B—Conge
C—Cyma Recta
D—Cyma Recta
E—Quarter Round
F—Ovolo
G—Echinus
H—Cyma Reversa
I—Half Round
J—Torus
K—Thumb
L—Half Hollow
M—Fillet
N—Bead
O—Scotia
P—Cavetto
Q—Scape
R—Cyma Recta
S—Cyma Reversa
T—Ovolo

CHAPTER IX.

ABUTMENTS, PIERS, AND BRIDGE DETAILS.

The design of abutments, piers, parapets, balustrades, and other details of both stone and steel bridges has been much more neglected in America than in Europe, but New York and some of the other large cities have adopted masonry standards of the highest excellence. The author has given the subject much attention in his various books on foundations, and in other engineering papers, so that an attempt will be made to classify all phases of the subject, to form a basis for the betterment of such details. While decrying the decoration of structures with inappropriate details from ordinary architecture, it must be understood that the use of the general proportions from classic architecture is usually necessary in engineering architecture. The proportions from classic entablatures are useful in designing cornices, while the use of the proportions from the bases of the Roman orders, is quite pleasing when applied to the design of parapets, balustrades, newels, or similar details, and the general features and proportions from all periods of architecture offer the most satisfying basis for the general proportions of engineering structures. The curves and moldings to be used in the base moldings and cappings of piers and other portions of engineering structures, are those employed by architects generally. These are shown on the opposite page and they are the cove or cavetto, the conge, the cyma recta, the quarter round, the ovolo, the echinus, the ogee or cyma reversa, the half round, the torus, the thumb, the half hollow, the fillet, the bead, the scotia, and the scape, with the modifications shown. The exact proportions of these can be obtained from the wonderful plates in Sir Banister Fletcher's History of Architecture, or from other well known books on architectural details.

The nomenclature of masonry can be obtained from various works on masonry construction, which also give the details of quarry faced and dressed stone construction, so that

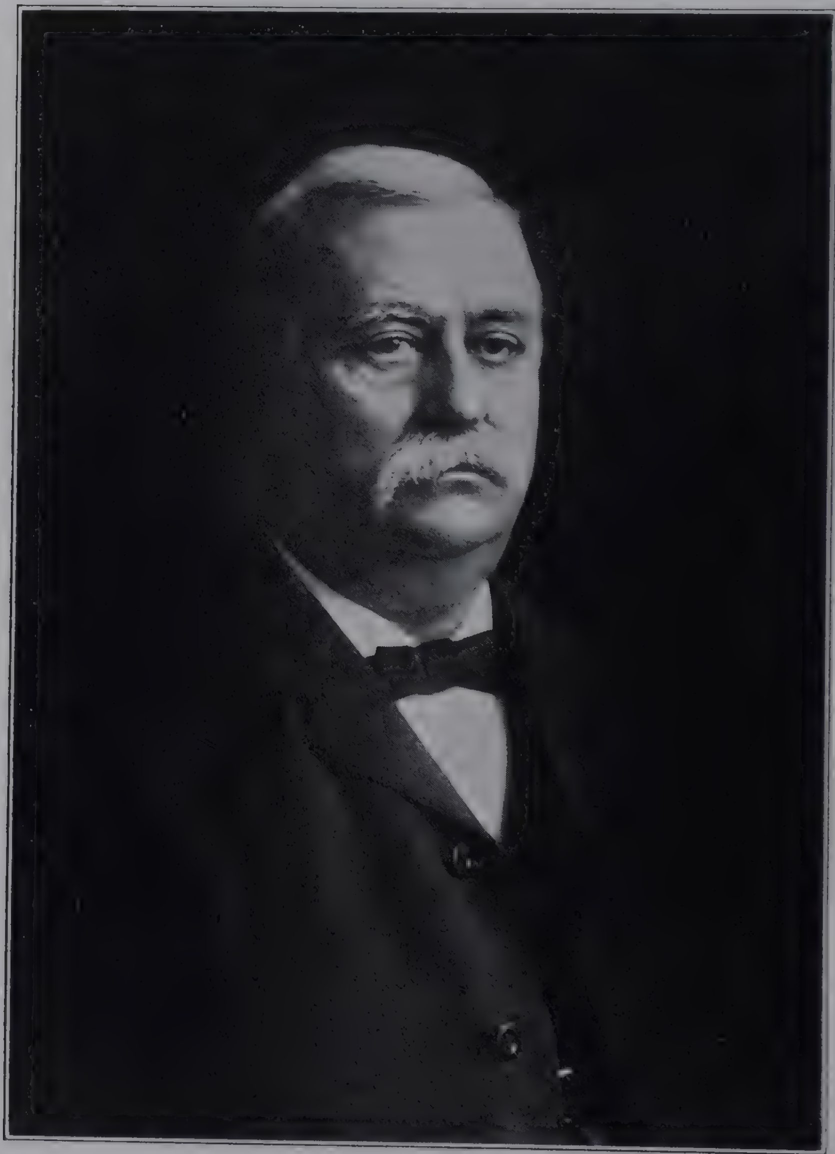


Morison Bridge Piers

Russian Bridge Pier

space will not be taken to repeat the details. The designer must consider very carefully just where to use cut stone work and cut stone details, as many pieces of construction have been ruined in appearance by incongruous combinations of dressed and quarry faced stone work, as was done in the great Luxembourg stone arch bridge as already described.

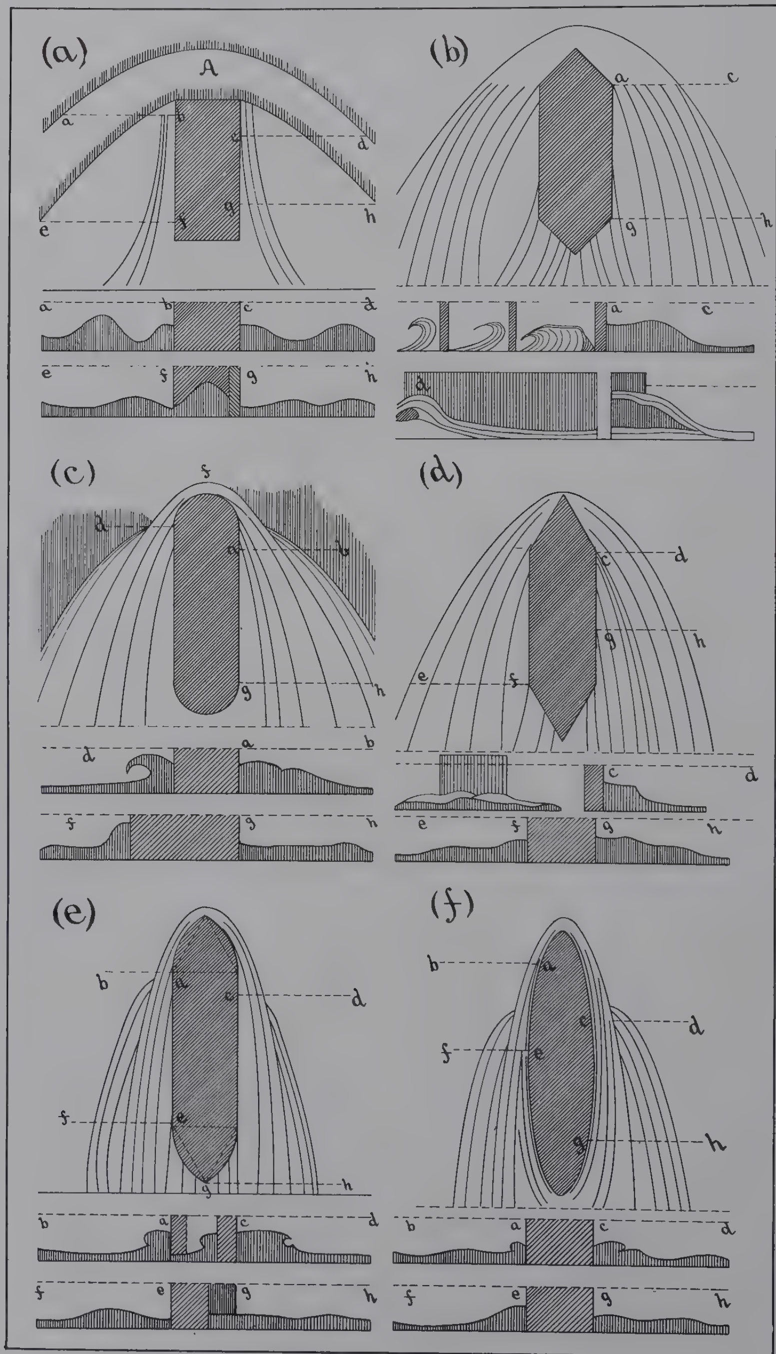
After deciding upon the number and location of the piers of a bridge, they must be designed with reference both to their being as slight obstructions to the water as possible, and as to their architectural appearance. Particular attention was given to the design of piers by the late Geo. S. Morison, consulting engineer, whose bridges across our great rivers are notable for their strength, simplicity, as well as finished appearance, and in a lecture he described the process of the design of some large piers. "Fourteen years ago I had occasion to design a bridge pier for a bridge across one of our Western rivers, and I tried to make an ornamental pier. When the plans were completed I did not like them. One change after another was made, all tending to simplicity. Finally the plans were done. From high water down, the pier was adapted to pass the water with the least disturbance; it had parallel sides and the ends were made of semi-circular arcs meeting. Above high water the ends were made semi-circular instead of being pointed. The pier was built throughout with a batter of one in twenty-four. A coping 2 feet wider than the body of the pier projected far enough to shed water, and the projection was divided between the coping and the (corbel) course below. Another coping with less projection surmounted the pointed ends where the shape was changed. It was as simple a pier as could be built, and in every way fitted to do its duty. I had started to make a handsome pier. The pier that was exactly what was wanted for the work, was the only one that satisfies the demands of beauty. Forty-three piers of precisely this design, no change having been made except in the varying dimensions required for different structures, besides eight others in which only the lower parts are modified, are now standing in eleven different bridges across three great Western rivers. In designing a pier it must be remembered that the portion of the pier below the water has more to do with the free passage of the water than that above water. In a deep river the model form of the pier



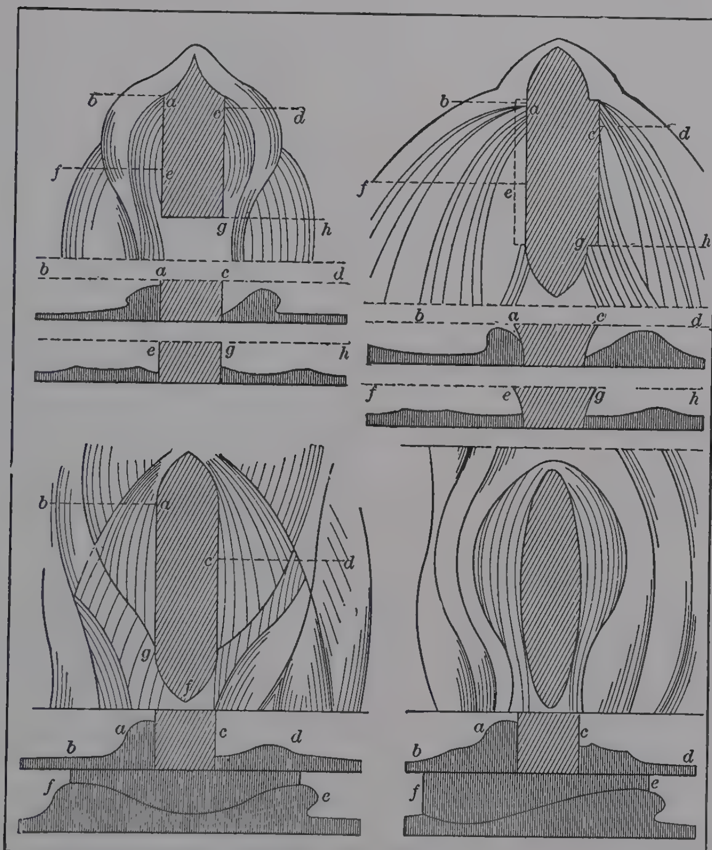
Alfred Noble

should begin near the bottom of the river and not at low water. Many rivers in flood time carry a great amount of drift. A pier like that which I have described catches but little of this drift. If, however, a rectangular foundation terminates but little below water, that foundation may both disturb the current and catch the drift." The piers of the Omaha bridge which carries the Union Pacific across the Missouri River are among the most beautiful piers in this country. In Europe, where money is more lavishly expended on great works of engineering, piers of great architectural beauty are much more frequent. The Russian Government railways, which were seemingly constructed without regard to expense, have many beautiful examples of bridge masonry and piers; one of them with curved ends, shows the elegant and massive character of the masonry. While extremely simple in design, the cut-stone coping and the molded corbel course below give it a finish which cannot be surpassed.

The design of piers for strength and stability is fully treated in "Sub Aqueous Foundations," but some experiments, which were made with reference to the proper form to occasion the least resistance, will be quoted at length from Cresy. The introduction of piers into a channel gives rise to a great disturbance in the velocity and flow of the water. Rapid currents are formed which cause the bed of the stream to become washed and the foundations to be endangered; eddies are created which are likewise undesirable, and it becomes necessary to adopt such a form for the ends of the piers that the disturbance to the flow shall be small. M. Bossut, in a French work on Jetties, thought to have solved this problem by mathematics, his conclusion being that the starling should be triangular, the nose being a right angle. M. Dubaut, in his "Principles of Hydraulics," gave another solution which was more nearly the truth, in that he arrived at the conclusion that the faces of the starling should be convex curves. The true form of this type is most nearly reached when these curves are tangent to the sides of the pier, and further than this, regard must be paid to giving enough solidity to the starlings to protect them from ice and drift. A happy medium would seem to be reached by making the curves with a radius equal to one-sixth of the circumference, described on the sides of an equilateral triangle.

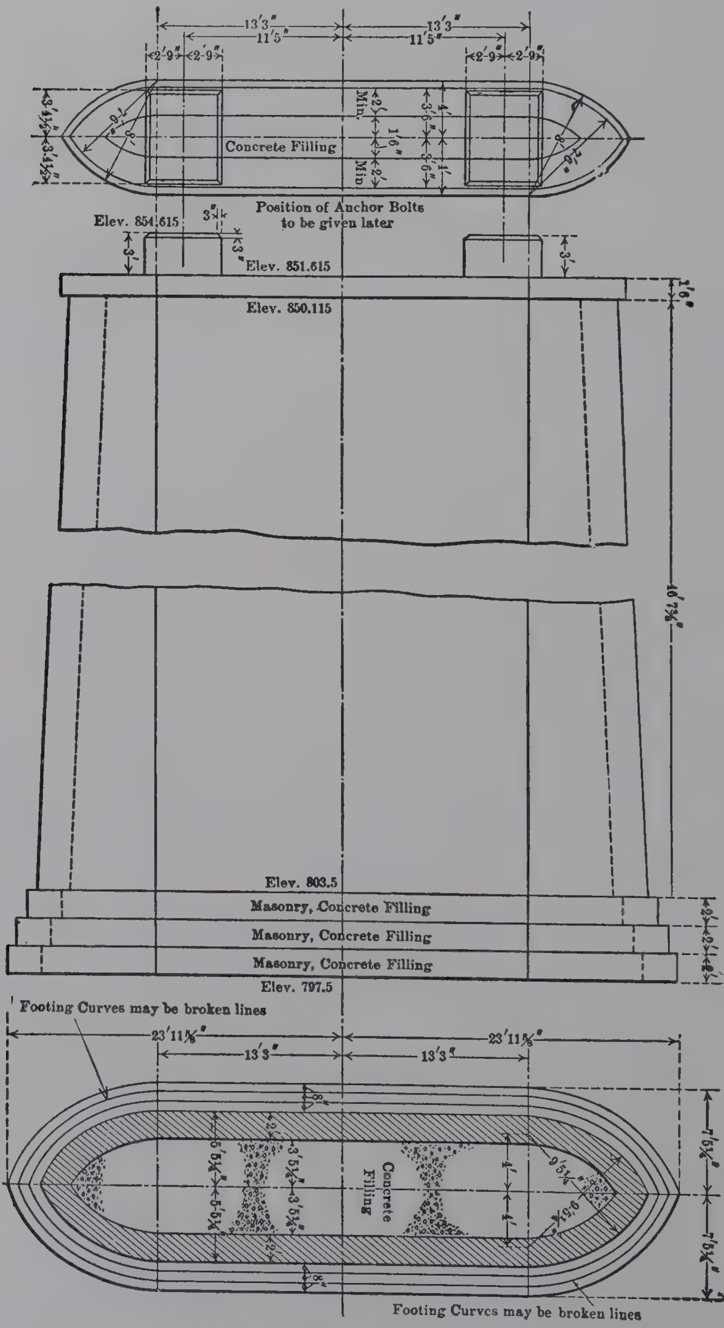


Form of Bridge Piers



FORM OF BRIDGE PIERS Figs (g) (h) (i) (j)

Experiments were made with models of different forms, which were placed in a rectangular canal between boards of 50 centimeters in length, in which the water flowed about 40 millimeters in height, the models being 15 centimeters in thickness. By means of a fall, the water was given a velocity of 3 meters 9 centimeters per second, the contraction, eddies, and currents being carefully measured. The first experiment was made on a pier (Fig. a) with rectangular starling. An eddy was formed before the pier 34 millimeters high, in a nearly circular band A, falling nearly vertical at the corner. There were two other currents along the faces of the pier, the height of which can be seen in the cross-sections. The second experiment (Fig. b) was with a triangular starling, the nose

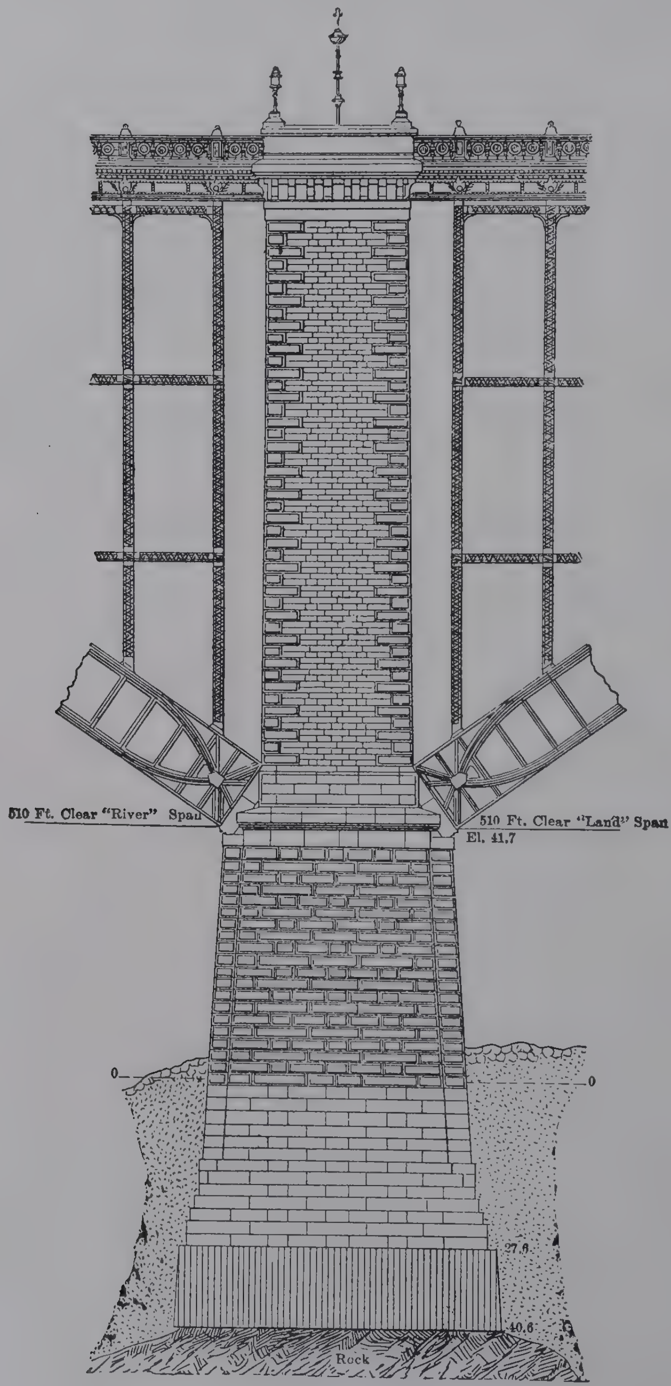


KNOXVILLE BRIDGE PIERS FOWLER

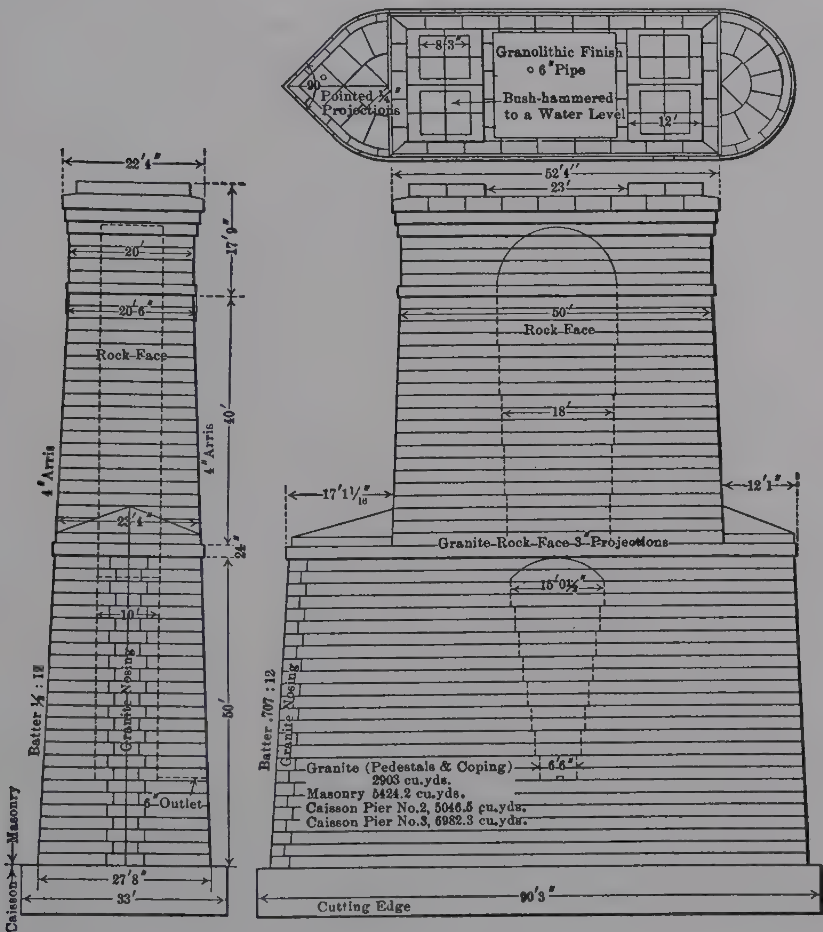
being a right angle. It formed a less obstruction than the square end, but the fall at the shoulder was as deep and more dangerous, while eddies were formed as seen in the sections. The third one (Fig. c) had a semi-circular starling, and while the eddy was not so wide, it was nearly as high. The fourth model had a triangular starling, with an angle of 60° at the nose (Fig. d). The eddy was less, as was also the fall at the shoulder. The starling in the fifth was formed by two circular arcs, tangent to the sides and described on the sides of an equilateral triangle (Fig. e). The eddy was small and there was no fall at the shoulder. The sixth (Fig. f) was a model, the plan of which was an ellipse, of which the small diameter was one-fourth the length, and the eddy was less than any of the others. The seventh model (Fig. g) had a starling with concave faces, such as is sometimes used where the wing-wall meets an abutment. It produced the most dangerous currents of all. The ninth and tenth experiments (Figs. h and i) were on the same forms as Figs. e and f, but the current had a velocity of 4 meters 87 centimeters per second, such as a river would have in its overflow. The eddy (Fig. h) rose to nearly twice the height, as was the case with the lesser velocity, and, while there was no fall, the inclination formed along the faces was more rapid.

The effect with this velocity on the elliptical pier (Fig. j) was similar to the lesser velocity, but more marked. It may thus be concluded that the elliptical section offers the least resistance to the current and occasions the least contraction, while the form with convex starling comes next, and of piers with triangular starlings the one with the 60° nose is the best.

Where ice is to be provided for, the nose or starling is often inclined to allow large cakes to mount it and break in two, without doing further damage. For any large or important structure, the design of the piers should receive a great deal of study, and be designed not only with reference to their theoretical form, but with reference to the form of pier which has shown the best results practically; has been found to be best suited to the velocity of the stream in which they are to be built, and to best withstand the drift and ice that may be met, while giving at the same time all the consideration possible to the architectural effect and to full har-



Washington Bridge Pier



St. Louis Bridge Pier

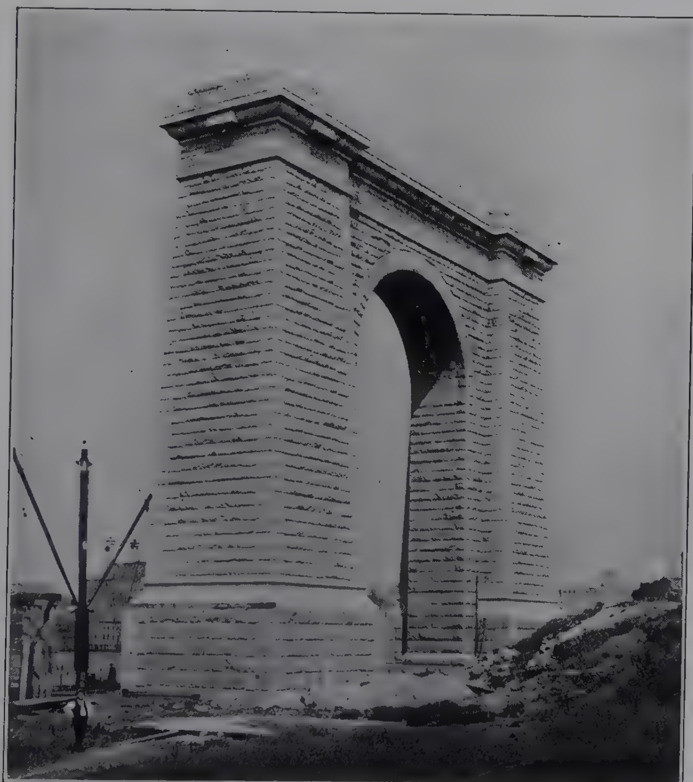
mony with the entire structure. The method of treating piers so that they may be considered artistic portions of a bridge must be decided upon, only after all the foregoing considerations have been most carefully weighed, and after a full investigation of what has been done in the past to make piers something more than mere supports for a superstructure. The fact that in a great majority of cases there has been nothing attempted towards the artistic, should not be allowed to influence a designer to abandon such efforts.

The channel piers of the Municipal Bridge at St. Louis

Tacoma Bridge Pier Fowler

Hell Gate Viaduct Piers

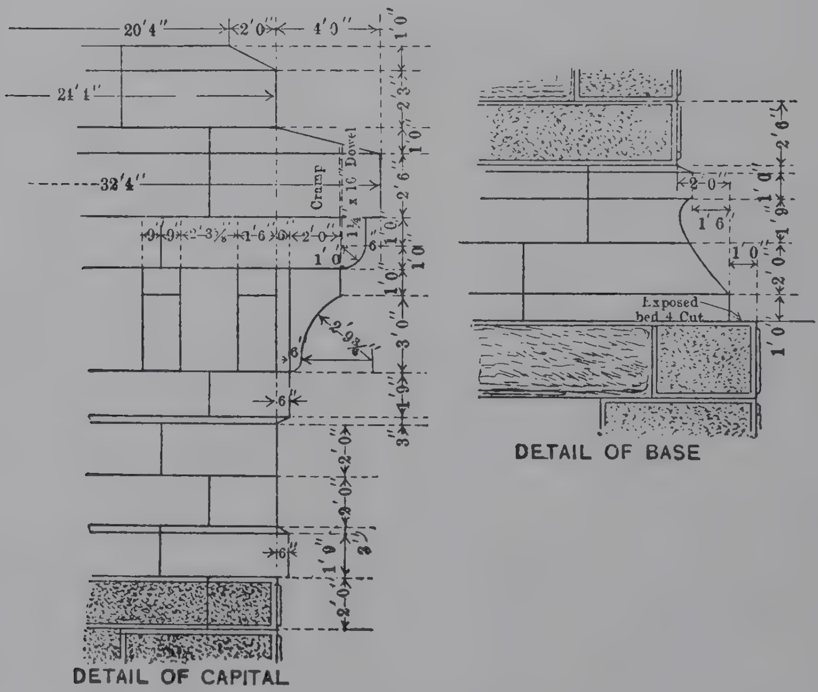
over the Mississippi, carry the adjacent ends of two 688-feet truss spans, and are correspondingly massive. They are 22 feet 2 inches by 52 feet 4 inches on top, and have a batter of 1 in. 24; with a curved end downstream below high-water mark, and a cut water upstream formed by a combination of circular arcs and straight lines as shown. The piers are of



Queensboro Bridge Pier

concrete, with rock facing, and having a granite nosing on the cut-water. The weight and quantity of masonry is reduced by a hollow space above high water, and a smaller hollow space below high water. The appearance of the piers is much enhanced by the double corbel course and by the offset just above high water mark. The piers were located by triangulating from base lines established on both sides of the river,

and the levels were obtained by establishing bench marks from both ends of Eads Bridge about one mile distant. The locations were checked by turning right angles to the Eads Bridge, correcting for temperature and grade, and the distances multiplied by the cosine of the angle between the two bridges. The results obtained were surprisingly close to the plan distances, being exactly the same for the west span, 0.03 feet difference for the center span, and 0.12 feet for the east span.



Queensboro Pier Details

The piers of the Knoxville cantilever bridge were five in number, and were built after the plan shown except for different lengths of shaft; and the shaft was only 19.9 feet for pier No. 6 on the south bank, which had one footing course 2 feet thick and a concrete base 16.7 feet thick on solid rock. The coping in each case was 18 inches thick. The piers were concrete filled and had a minimum thickness of iron limestone as shown on the drawing, with the inner faces of the stones

in each course left rough and projecting into the concrete core varying distances to form a proper bond. The outer faces of the piers were rough rock faced, but the appearance of the piers could have been very much improved had money been available for corbel courses and other cut stone work to enclose the bridge seats. The cross-section of the piers had ends formed of two intersecting arcs of circles, and as the piers extended but a short distance above extreme high water, the same cross-section was used for the entire shaft. The data and plans are taken from the author's record of the construction of the bridge.

The main piers of the Blackwell's Island cantilever bridge are twin-arched piers, and are of the very best design and detailing. They consist of two main shafts, connected by an arch resting on pilasters, carefully bonded together. The facing is of rock faced Maine granite, with limestone and concrete backing. The corners of the shafts are quoins, varying uniformly in size from base to capital. The faces of the shafts have a batter of 1 to 24, while the faces of the sub-base, the pilaster, and spandrel walls are vertical. The bases courses proper and the capitals are of four-cut work, and rough pointed, with 2-inch marginal draft. The masonry in general is ashlar with Flemish bond. The face of the headers is never less than the height of the course, and the length at least two and one-half times height. The face of the stretchers is not less than twice the height of the course, the width not less than one and one-quarter times the height, and they were required to hold their full face thickness for the entire width. The quoins were made to the dimensions shown on the plans, the faces were pointed to 1-inch projections, and all the exposed edges have a 2-inch margin draft. The quoins on the bases and shafts stand out 2 inches beyond the pitch lines of the ashlar. The ring stones of the arches were set flush, with the arch sheeting and stand out 2 inches beyond the face of the spandrel wall. The soffits of the ring stones were fine pointed and the faces rough pointed, with a 2-inch margin draft all around. Especial attention is called to the careful layout of all the molded courses, which give the piers their finish and add much to their fine appearance.

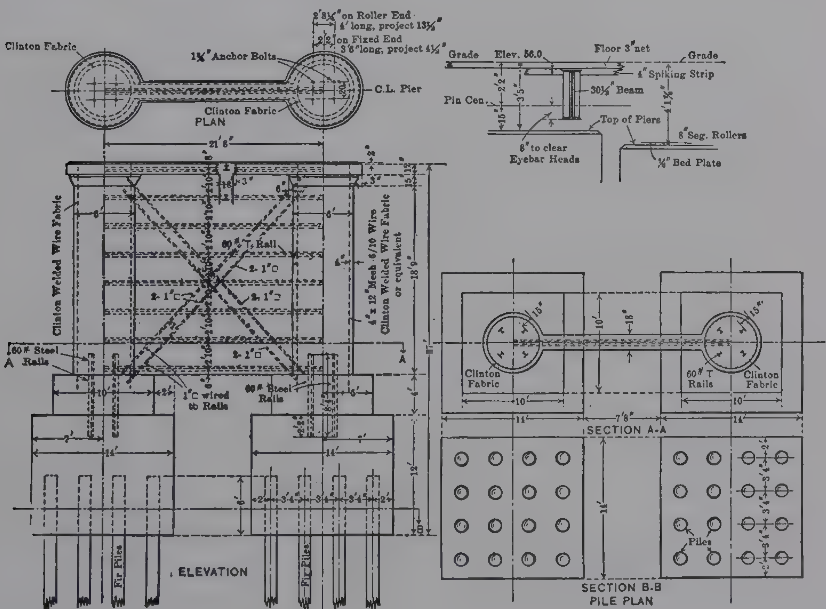
The embankment type of construction was not practicable

for the entire approach to Lindenthal's Hell Gate Arch south of 138 Street, because, on account of the greater height, the foundation pressures would have become excessive. The plate-girder type of viaduct, with concrete piers, was adopted as being most suitable. The spans are generally about 64 feet long, except over the street, where they had to be from 72 to 112 feet. The piers are of plain rectangular shape, with simple square copings. The general conditions which affected the design of the viaducts in the Bronx section south of 132nd Street, on Randall's and Ward's Islands, and on Long Island north of Lawrence Street, are similar, with the exception of the character of the soil. The fact that these four sections are prominently exposed to view called for a uniform and pleasing appearance, in harmony with the monumental character of the great arch bridge which they flank on both sides. The type of viaduct adopted consists of deep plate-girder spans resting on arched concrete piers. The span length varies from 72 to 94 feet, except for a single opening over one avenue in Long Island, which is of 130 feet span. The lengths chosen are the most economical, except on the Long Island viaduct, where they were largely determined by the location of the many streets which had to be crossed.

The very simple but pleasing cylinder piers shown were designed for a 380 feet highway bridge at Bellingham, Washington, and are of reinforced concrete of a type patented by the author. The foundation for the piers illustrated was of 16 piles in a crib for each shaft, with a concrete base 14 by 14 feet and 12 feet deep. The footing course is 10 by 10 feet by 4 feet thick which carries the shaft of 6 feet in diameter. The shaft is anchored down by four 60-pound rails, and the same sized rails are placed in the 18-inch webs as reinforcing and to tie the shafts together. Diagonal shear reinforcing of the web is also used, and the shafts are reinforced just inside the faces by Clinton electrically welded wire fabric. These piers have a somewhat ornamental top, through the use of the simple corbel course. Piers of this type when used in a channel, offer somewhat more stream resistance than the best forms of solid masonry piers, but usually this is a negligible matter, unless the spans are short and the number or width of piers takes up a large amount of the waterway. The large

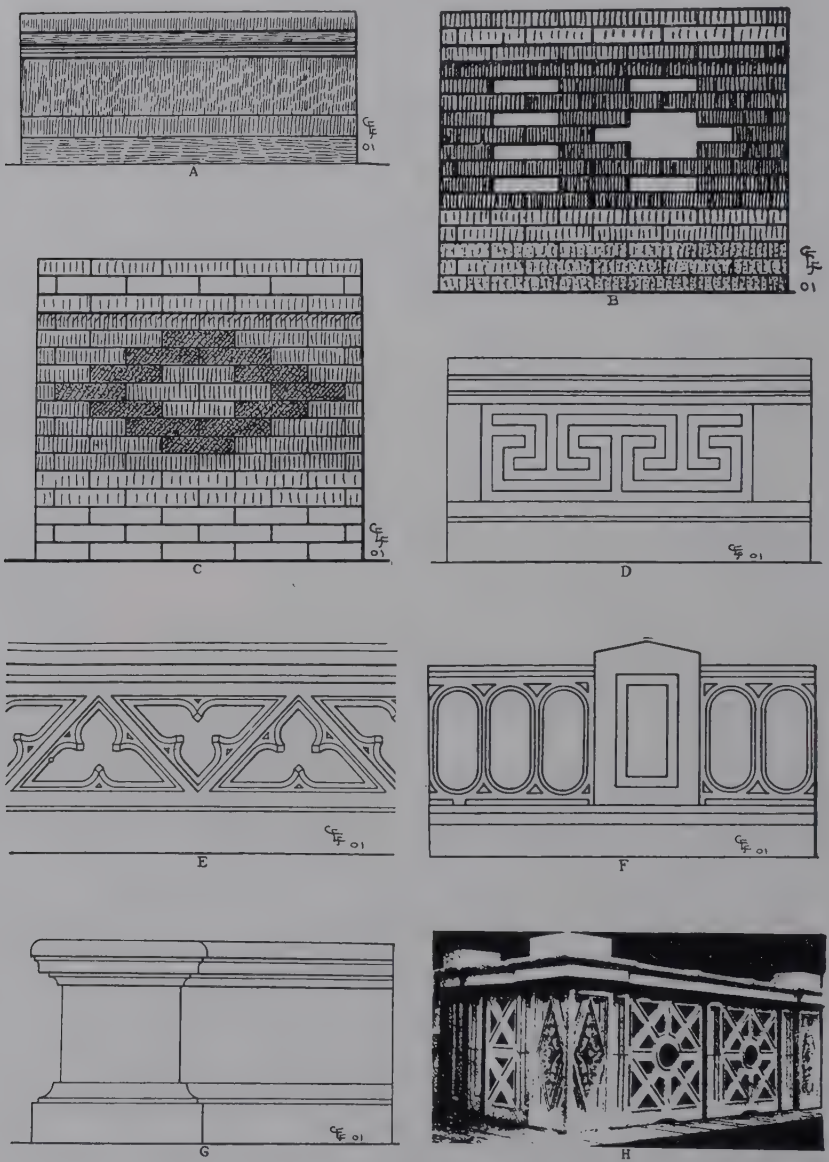
and high piers of the Tacoma Bridge built by the author are of the same type, except the method of reinforcing the webs, and that no reinforcing was used in the shafts. The batter is ½ inch to the foot and the web between the shafts which is 2 feet thick at the top is also battered. The foundations extend 160 feet below high tide, and the piers rise about 90 feet above the water.

The Washington Bridge over the Harlem river in New York City is in many respects one of the finest pieces of bridge



Bellingham Concrete Piers Fowler

architecture in the world, especially in details, and the masonry is particularly notable for its solid construction, and the perfection of its design and detailing. The center pier is especially notable, as it carries the adjacent ends of the two 510-feet two-hinged steel-arch spans. The masonry is of concrete, faced with Maine granite in from 2 to 3 feet courses, having as much bed as rise and laid with ½-inch joints. The quoins are rock faced from 3 to 6 feet on the front, and have a 2-inch flat draft around the face. The shaft of the pier



TYPES OF BRIDGE PARAPETS

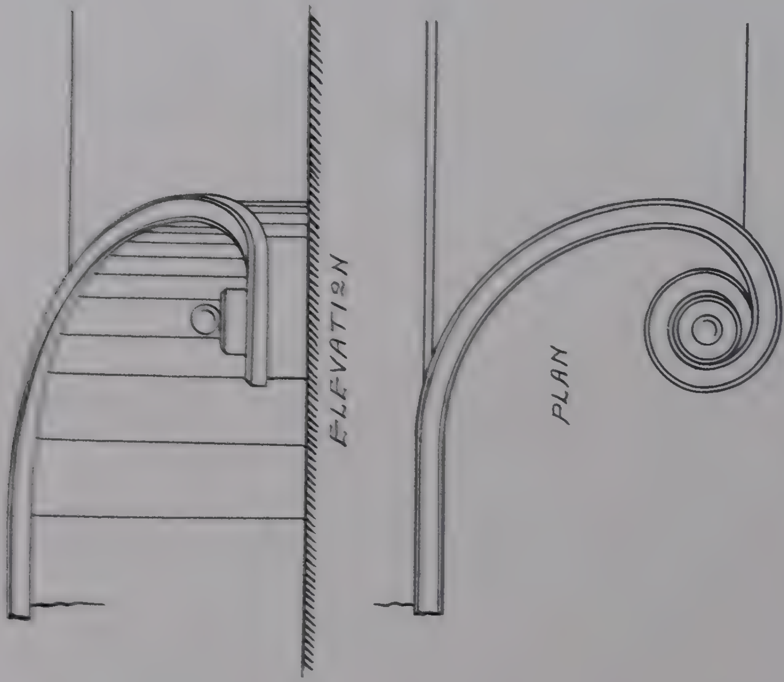
A—Plain Classic	C—Tint Brick	E—Triangular	G—Plain
B—Open Dado	D—Grecian	F—Oval	H—Paneled

is 25 by 90 feet, and the base is 36.55 by 100.16 feet. The skewbacks are only net size 4 feet 4 inches by 13 feet, and the appearance would have been much improved by making them with considerably more margin around the steel shoes. The details of the skewback courses and of the cornice shown are especially worthy of study and emulation in the designing of new work. They are of cut stone and add very largely to the general appearance of the masonry and of the whole bridge.

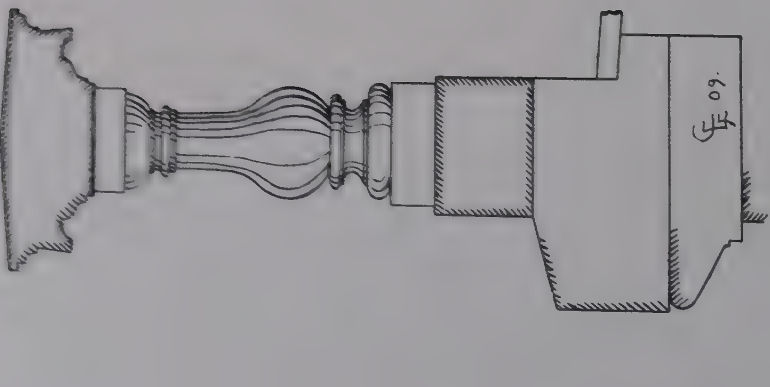
The design of abutments for a structure should of course harmonize with the piers, both in general appearance and in detail. Where they retain a high fill, they must have wing-walls, whether straight out sidewise, backward at an angle,

Wheeling Stone Parapet

or straight back to form a "U" abutment. The anchorages of the Manhattan Suspension Bridge in New York City are of the type of abutments, and should be very carefully studied as to the details, which are very well executed. The two latter types of wing walls can usually be changed for artistic betterment by using a circular or spiral curve in plan, tapering down vertically to meet the slope of the fill a few feet above the ground level. Such a design is susceptible of being made quite beautiful, although using very little decoration and retaining the greatest simplicity, to harmonize with masonry arch spans of chaste character. The "U" abutment is naturally of a somewhat monumental character, and the most



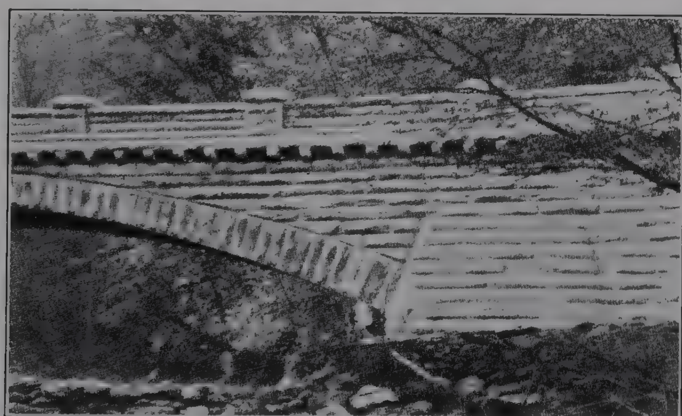
Spiral Wing Wall Fowler



Turned Baluster

that can properly be done is to retain the motif of simplicity, with only a chaste detailing of the base, corbel, and coping courses, with a harmonious parapet or balustrade.

The balustrades of bridges are most pleasing when as simple a design is used as will be in harmony with the structure. The same principle applies to the parapet on a stone arched approach to a steel bridge, and splendid examples are the parapet balustrades of the Washington Bridge over the Harlem, or the Westminster Bridge over the Thames. Where stone is used, the dado or center portion of the parapet wall should be made solid, as the effect will be just as good, and the cost much less; if brick is used, the dado may be laid with



Wissahickon Stone Parapet

open work, or else different colors of brick may be used and a pattern worked into the construction, although the contrast should be slight or else the result will be too glaring; where cement or terra cotta work is employed, the solid dado may have panels of relief work with fine effect. The extreme ends of the approach parapets and the ends next to the bridge itself should be terminated by larger plain panels or pedestals of harmonious and appropriate character. The proportions used should be decided upon with reference to the general style of the structure, the simpler and plainer the design the more likely it will be to please for a long period of time. The proportions of the pedestals of the Roman classic columns have

Knoxville Concrete Parapet Fowler

Yosemite Dam Balustrade

been used with splendid success in establishing the dimensions for the plinth, dado and capping of parapets, the whole being coped or covered with a simple cap.

The design of the parapet for masonry arches should be such as will give the best effect to the arch itself. Where the depth of the center is very shallow the parapet should be of solid or close construction similar to that on the Wheeling arch, which is a simple design of stone wall with a plain coping, or like that of the Wissahickon arch at Philadelphia, with pedestals at frequent intervals. Another example of a solid parapet where the work is of cut stone, instead of rock face, is that of the Darlaston Bridge, the base and coping having chamfered edges. Where dressed stone is used the dado may be divided into panels, with decorations in relief, as was mentioned for approach parapets, or a solid effect may be obtained by the use of a design similar to the parapet of the Ouse Valley Viaduct in England, the base being beveled on the outer edge and supporting a series of small arches, above which is a top course with chamfered edge and an ornamental cap with curved top. This design would also be the type to use where the depth of the arch at the center is only moderately great; but where the depth is great an open parapet railing or balustrade should be used, an extreme case being the Croton Aqueduct High Bridge at New York, where the depth over the crown of the arch being so great to allow room for the water pipes, a light cast iron railing is a fairly appropriate parapet. The cast iron parapet, used on the Gerrard's Hostel Bridge at Cambridge, England, is an elegant design with open dado of lozenge pattern, and heavy enough for a span with only moderate depth.

The most notable bridges have parapets of more elaborate design and quite expensive construction, using frequently a balustrade with turned stone balusters. The Wellesley Bridge at Limerick, designed by Mr. A. Nimmo, is one of the handsomest bridges in the British Isles. There are five elliptical spans of 70 feet each, surmounted by an elegant balustrade, there being two pilasters over each arch dividing the balustrade into three portions over each span, with pedestals at the extreme ends and over each pier. The recently constructed

Schenley Park Bridge at Pittsburgh has one of the handsomest similar balustrades with turned stone balusters, in this country. They are more frequently employed on European work than elsewhere, the oldest examples probably being the bridges of Venice and notably the Bridge of the Rialto. The Auteil Viaduct at Paris also has such a balustrade, as have numbers of other French bridges. One might, therefore, conclude that this forms the most appropriate parapet railing for an elaborate stone bridge. The new bridge at Ayr, Scotland, has a parapet of stone in which the dado is decorated with moulded circular openings and such other details so as to make a handsome design. The parapet has pedestals at the ends and over the piers surmounted by lamps, and five intermediate pilasters or pedestals over each arch. The railing or balustrade of bronze used over the spans of the Washington Bridge in New York City, is of a design which gives a similar effect. The use of simple battlemented parapets has been used on many bridges with good effect, but are more suitable for a railway bridge than for a highway structure, unless the embrasures were filled with simple iron pickets. Toll or gate houses are much employed at the extreme ends of parapets of old bridges and also at the present, when toll bridges are more numerous; and some of the more recent bridges have used large end pedestals in imitation of these, but they should be of simple design, unobstrusive in size and harmonious with the parapets and the structure itself.

CHAPTER X.

DESIGN OF STONE TOWERS AND LIGHTHOUSES.

The earliest example of a well designed stone tower in America, is the old Stone Mill at Newport, Rhode Island, which the author was raised to believe was built by the Norsemen about the year one thousand. Upon a personal examination it was clear that if it was built as a result of the Norse expedition they must have had both a good architect and an expert engineer in the party. However it developed upon careful investigation that the tower was most likely built under the elder Benedict Arnold about 1675, when he was Governor of the colony, as a wind driven grist mill. He came from near Chestertown, England, where there was an almost identical structure built for Sir Edward Peyto in 1632, from the designs of the famous English architect, Inigo Jones. The masonry is in very good condition for two hundred and fifty years of age, and one surmises that it was built by day labor, regardless of cost, considering the stone work used, which was a coarse rubble of laminated slate or graywacke mixed with gneiss.

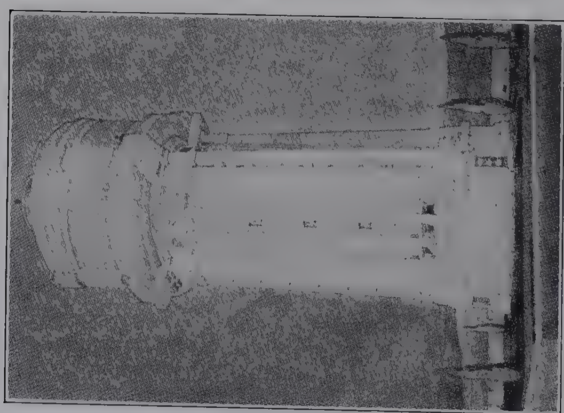
The diameter from outside to outside of the six circular supporting columns is 24 feet 8 inches, while the diameter of the upper circular wall is 19 feet 9 inches. The columns are from 38 to 40 inches in diameter, and have a height of from 8 feet to 8 feet 8 inches above the ground to the top of the single rounded cap stones, while the height to the intrados of the arches, which are sprung from column to column, is 11 feet 2 inches. The distance to the fireplace hearth level is 13 feet 5 inches above the ground, while it is 25 feet to the top of the wall, and the second floor is 20 feet 2 inches from the ground level. The fireplace is 3 feet 5 inches by 4 feet wide, the south window 2 ft. 2 in. by 2 ft. 5½ in. high; the west window 2 ft. 2 in. and 16 feet above the ground. The stone work now remaining is most impressive and pleasing, and if it once appeared with roof and vanes as in the restoration, it is a worthy artistic predecessor of all subsequent American towers.

OLD STONE TOWER NEWPORT R. I.

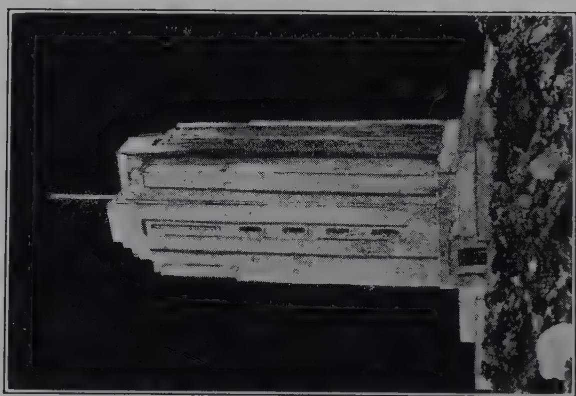
The ordinary American water tower is far from a thing of beauty, as may be seen from the one built by the author at Fort Stevens, Oregon, from plans of the War Department,

NEWPORT TOWER RESTORED

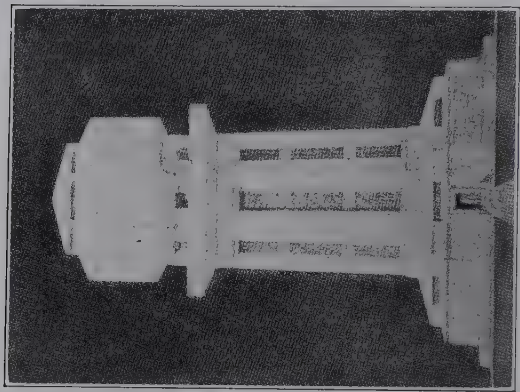
which is simply a big circular steel tank, supported by braced steel columns. The tanks of this kind on apartment houses and business buildings in our cities are most unsightly, and it has been a very recent step to enclose such tanks in artistic



Water Tower
First Prize

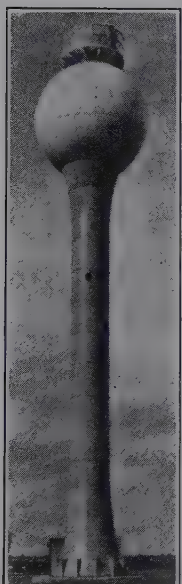


Water Tower
Second Prize



Water Tower
Third Prize

pent houses, which add to, instead of detracting from, the architectural effect of otherwise monumental buildings. The effort to get away from such unsightly towers as the one at



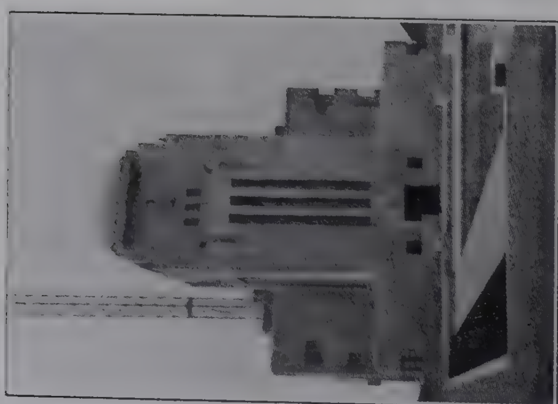
Steel Tower
Ponca City
Okla.

Fort Stevens Tank Fowler

Fort Stevens is being made more frequently than in the past, and a competition was recently held in England for the design of a water tower. There were a number of designs submitted, and a first, second, and third prize awarded. The third prize was awarded to a design which was more truth telling than beautiful, as it disclosed the ugly tank and tower in outline, which thus became only a covering as an attempt at ornamentation. The design receiving first prize was somewhat better than the third, as may be seen, but of the same type. The one receiving second prize was certainly the best of the three, as it transformed the structure into a monumental

Einstein Tower

Prado Water Tower



Holland Radio Tower

tower, which had simplicity, harmony, and proportion, while still disclosing its purpose. There is no need when following out the idea of having a structure truth telling, to have such features brutally emphasized.

The stone tower to enclose a tank in the cemetery at Hawthorne, New York, was designed by Charles W. Leavitt, Landscape Engineer, and is a most artistic creation of mediaeval type, in the design of which the unbalanced feature of the

Hawthorne Water Tower

small and higher tower has been made to remove any flatness in the appearance of the entire design. The stone and brick tower at Manistique, Michigan, is a quite simple and chaste one, with paneled sides, and a well detailed cornice of good proportions, surmounted by a dome shaped roof. While it is vitally different from the one at Hawthorne, and not of so artistic a character, it marks a distinct advance over the unenclosed tank. The Prado water tower in Florida, is of Spanish design, and for that reason a very interesting innovation, although the top balcony and the design of the roof suggest a lighthouse on the Spanish Main, rather than a water tower. The water tower which stands on the bluff overlooking High

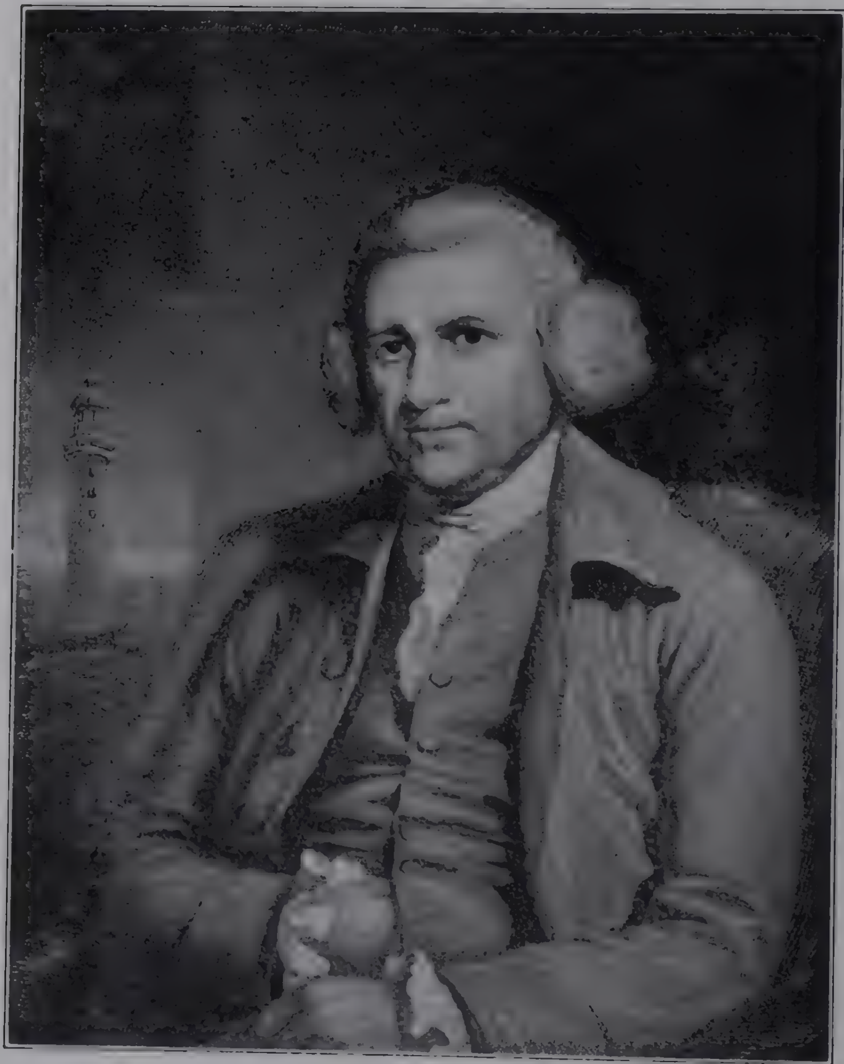
Perry Monument Put-in-Bay

Bridge and the Harlem River in New York City is of simple design, but one of the most pleasing in America, and the tower in Eden Park at Cincinnati is another one of similar type, which adds much to the scenic effect of one of the most interesting of American parks. The whole problem of water tower design is to reject the bare tower and tank, and to design covering as well as carrying towers, which will be inexpensive, at the least sightly and pleasing if the artistic

Harlem Water Tower

cannot be attained, and which will fully harmonize with the surroundings, as does the tower at the Vwrny dam of the Liverpool waterworks.

The Einstein Tower at Potsdam, Germany, is of a very odd and interesting design by the German architect, Erich Mendelsohn. It might well be a bit from out of the universe,



John Smeaton

heralding the Einstein theory. The engineer can study it with profit as a contribution to boldness and to a notable monolithic character. The Radio Tower at Kootwyk, Holland, is a symmetrical structure, of simplicity, harmony, and good proportion. Such a design of outstanding simplicity, is much more appropriate for an engineering structure than one with much decoration, or with anything of a frivolous character.

MANISTIQUE TOWER

The first lighthouse regularly maintained was one at the present Cape Incihisari about 660 B. C. and others were undoubtedly built by the Libyans and Cushites of Egypt. The great Pharos of Alexandria has already been described, and whether it was of 600 feet height or much less, it was one of the seven wonders of the world, and remains today as the legendary beginning of modern lighthouses to guide the early

OLD CORDOUAN LIGHT

ISLE VIERGE LIGHT

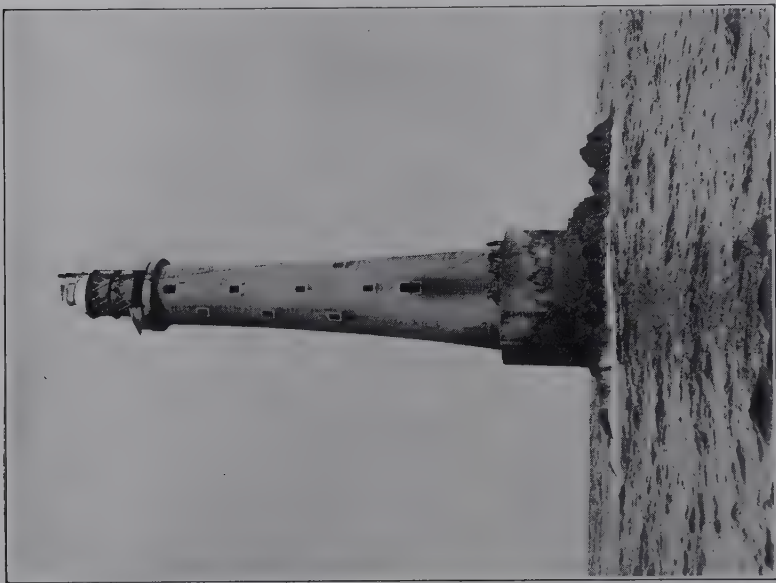
BELL ROCK LIGHT

LIGHTHOUSE ERITREA

mariners to their havens. Such light beacons were of a very picturesque and romantic nature, as the risks of navigation at that time were very much greater proportionately than they are at the present. While the Mediterranean world of that time became dotted over with Pharos as commerce grew, the first real lighthouse to be built which is yet in use is the Cor-

Eden Park Tower

douan light at the mouth of the Gironde in France, and it was on a rock where it was wave swept. There are legends of earlier lights on the rock, one built by Louis Le Debonnaire in 805, and another by Edward the Black Prince. The one still there is in part the one begun by Henri II in 1584, and completed by Henri IV in 1611. It was of beautiful Renais-



Bishop Rock Lighthouse

New Cordouan Light

sance design, which was and is hardly appropriate for such a purpose. There were four stories, stepping in at each level, and the fourth story was crowned by the light, which might be termed a fifth one. The shorter bottom story had Doric columns carrying an entablature, while the second was Ionic. The third story was decorated with Corinthian columns, and the lantern story was of the Composite order. The height was 169 feet, the base of the foundation was a 135 feet circle, the top or platform of the base a circle of 125 feet, and the diam-

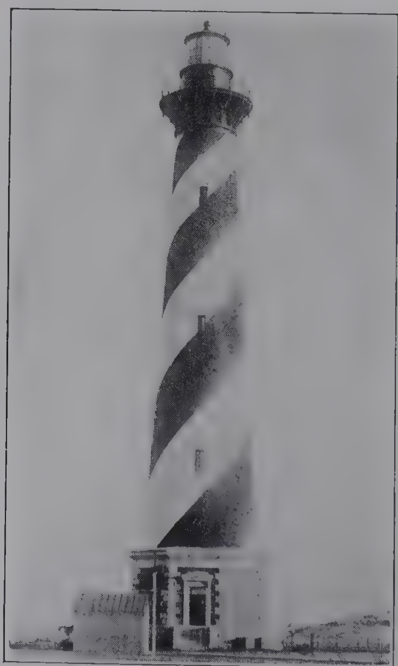
White Shoal Light

San Pedro Cal. Light

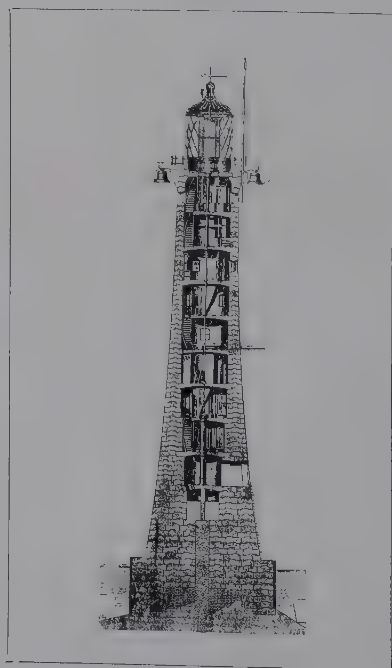
eter of the top of the 12 feet step on which the tower was built was about 100 feet in diameter. This step was to break the force of the waves, according to the plans of the builder Louis de Foix, but it is likely that the steps and great mass of detail of the various stories were equally effective for this purpose. The two upper stories were removed at the end of the eighteenth century, and the tower now rises to a height of 207 feet above the rock, but with the four molded cornice courses in the height of the new shaft, the effect of the lighthouse is still very pleasing and artistic.

Old Eddystone Light

New Eddystone Light



Cape Hatteras Light



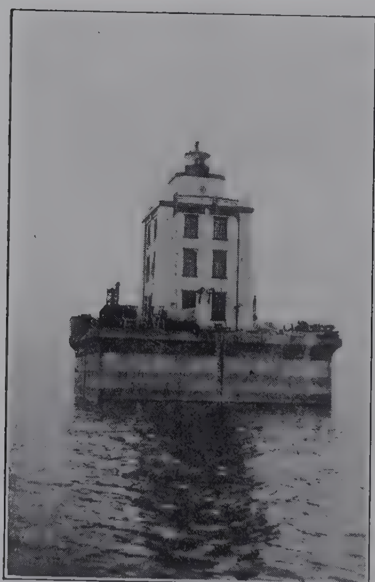
Eddystone Section

The Eddystone rocks off Plymouth, England, have been the site of four famous lighthouses. The first or Winstanley tower built in 1695, was of quite elaborate and supposedly good design and quite inadequate to withstand the storms, being reinforced extensively, but finally swept away by a storm

in 1703. The second or Rudyerd light was much more sturdy in construction, but it was destroyed by fire in the year 1755. The third was built by Smeaton the famous engineer, in 1756 to 1759, with a height to the focal plane of 72 feet, but after much reinforcing it was found unsafe in 1877, due to the rock

MINOT'S LEDGE BOSTON

STATUE OF LIBERTY



MARTIN'S REEF LIGHT

RACINE REEF LIGHT

ledge being undermined, and it was replaced by the Douglass tower which was put in use in 1882, and which is located 120 feet away from the site of the Smeaton light. The 44 feet base is a vertical cylinder for a height of 22 feet to break the waves, then the shaft rises in the form of a concave elliptic frustum to the stone cornice, with the light at a height of 133 feet above high tide, and a total height of about 160 feet. While severely plain in design and with no artistic features except the vertical elliptical curve and the simple cornice, it is a most majestic and inspiring structure. The Bell Rock lighthouse 100 feet high, off the coast of Forfarshire, is of much more pleasing outline, with a more sweeping vertical curve and consequently a much greater proportionate spread of base. The work was begun in the year 1807, and finished in 1810, under Robert Stevenson, the father of the novelist, with Sir John Rennie as Consulting Engineer. The Bishop Rock lighthouse occupies what is perhaps the most exposed situation in the world at the most western part of the Scilly Islands. It was built in 1858 from the plans of James Walker, but while very graceful, it was so light as to need reinforcing, and this was done upon the same outline used at Eddystone by Sir J. N. Douglass, by encasing the old tower in granite, with a rise in the height of 146 feet to the light and a total of about 170 feet. The appearance of the tower artistically depends solely on its simplicity. The Skerryvore light built by Alan Stevenson in 1844, is a very graceful structure and with a somewhat more elaborate cornice. The location is off the coast of Argyllshire, and the height is about 165 feet, which is attained by the artistic hyperbolic curve of the shaft, and a neat but plain lantern story.

The Cordouan light off the French coast has already been described, and while there are many notable French lighthouses, the other most imposing one is that for the Isle Vierge light off the coast of Finistere, which is over 250 feet high. The rectangular base rises from the same level as the old light tower, and the lower section up to the belt course is of quarry faced rock, which gives the base a very rugged and solid appearance. The cut stone shaft of circular form, tapers up to the beautiful cornice with its molded brackets and is accentuated by the molded belt course just below. The lantern

story is much more artistically designed than usual, and the domed roof with neat finial adds much to the very artistic ensemble of the entire structure. The use of vertical curves in lighthouse design is often necessary for exposed locations, and it has been noted how much the greater curve added to the appearance of the Bell Rock tower. When it is possible to make the shaft as slender proportionately as the author showed in the lighthouse on the Phebe Hobson Fowler medal, and to adopt somewhat of the detail of the Finistere shaft, with three high up windows as shown on the medal, a very fine work of engineering may be attained.

The American lighthouses are too often of the type of the Minot's Ledge light off Boston, and they would be more pleasing if more attention could be given to designing than is shown by such bare and forbidding towers; with too seldom such attempts as were made on the Great Lakes, where one lighthouse was patterned after that of Cordouan by the superintendent, E. L. Woodruff, M. Am. Soc. C. E., who also made efforts to make all the lights under his jurisdiction of more pleasing appearance. The Perry Monument at Put-in-Bay on Lake Erie is in reality a beacon, and the huge fluted Doric column, carrying the beautiful bronze lantern, after the manner of the Pharos of Alexandria, should be given consideration when the design of artistic lighthouses is being attempted by the officials, who should take a page from Trinity House in England, and another from the Commission des Phares of France, to which country America is indebted for Bartholdi's great Statue of Liberty in New York Harbor. This is essentially a beacon like that of Rhodes, and besides being a wonderful piece of the sculptor's art, it is worthy of much study, especially the stone base, which was constructed of masonry by the Corps of Engineers of the United States War Department, who also constructed the steel frame work which supports the figure. The stone work is of an especially fine design and workmanship, and besides being very simple and chaste in design, it is quite harmonious for such a great monumental purpose, and with its great figure of Liberty.

CHAPTER XI.

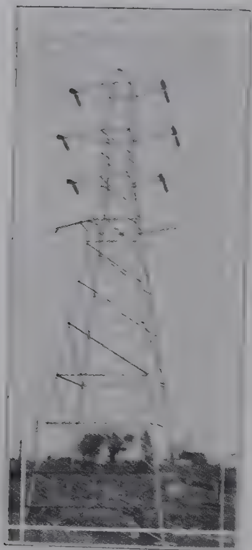
DESIGN OF STEEL TOWERS.

The design of steel towers for suspension bridges has already been discussed in the chapter on that type of bridges, and the same fundamental principles as indicated for them, should be applied to any sort of steel tower that is to have an artistic appearance. The many framed towers which have been built everywhere, have mostly been designed without any thought whatever being given to their being of beautiful outline and appearance, instead of being the blots which they are in many vistas and landscapes. Perhaps this is due to a too utilitarian period in our history, when bill boards intrude everywhere, and unsightly structures and factories are the rule and not the exception. The entering wedge for a more beautiful environment, may be the careful and artistic design of towers for transmission lines, for radio use, for mooring masts for dirigibles, for airway beacons, and all similar purposes, where the aesthetic idea should rule, in an endeavor to awaken the latent artistic ideals of mankind.

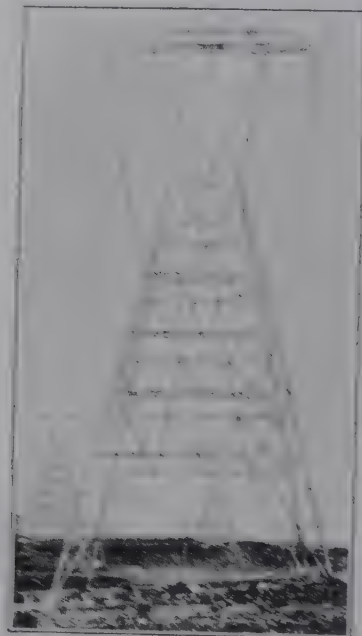
The prototype of all such structures is the Eiffel Tower in Paris, rising to a height of nearly one thousand feet in the most graceful, pleasing, and artistic outline ever given to any tower of the past or present. The great arches of the first story, are artistic and most appropriate for supporting the gossamer like structure of the upper stories, and the beautiful shaft that reaches the clouds, at a height of 300 meters or 984 feet. The height to the first landing is 184 feet, and to the second 376 feet, while the total height surpasses the Washington Monument by 429 feet, and St. Paul's in London by 580 feet. The square of the base is 100 meters or 328 feet, and thus it covers an area of nearly 2½ acres. The gallery at the lantern floor is 5 meters in diameter. The construction was begun under the famous French engineer Gustave Eiffel in January 1887, and completed on March 13th, 1889. The tower was built mainly for observation, but is now used for

Alexandre Gustave Eiffel

The Eiffel Tower Paris

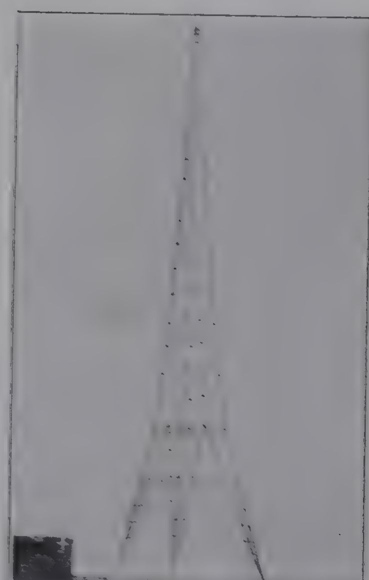


Plain Power Tower



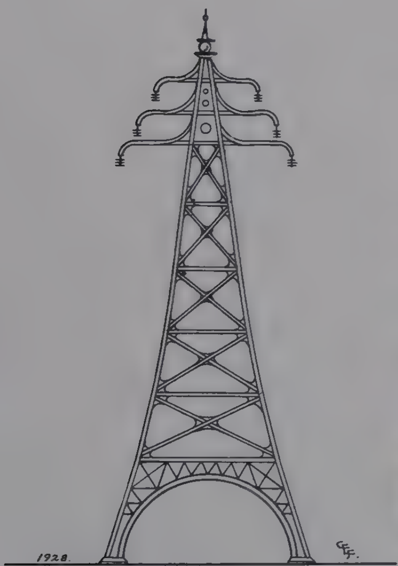
Large Power Tower

Power Line Tower

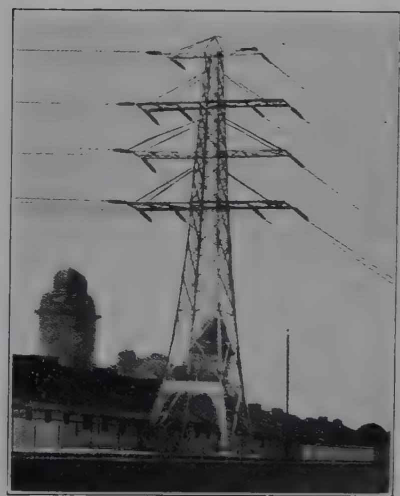


Usual Tower Type

many scientific purposes, such as meteorological investigations, for radio transmission, and as an airway beacon. The entire structure may be considered as a work of engineering architecture in its entirety, and well illustrates the possibilities of applying purely basic artistic ideas to the design of any engineering structure, without finding any necessity for decoration with classic details or any others which might seem to be extraneous. The straight lines of the smaller members



Suggested Design of
Power Tower

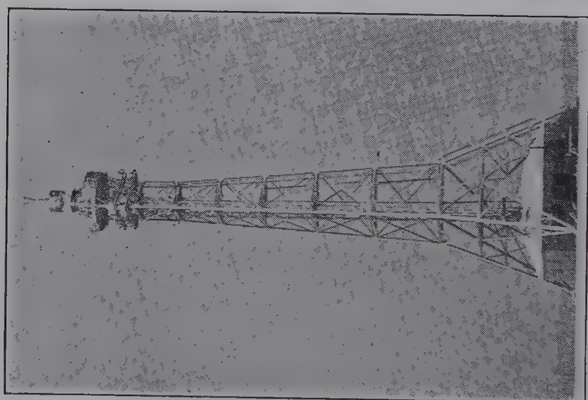


Curved Tower

and of the lattice work seem to melt into the insensible curves of the structure, as the web of an exquisite piece of lace becomes a part of a beautiful pattern. While it was a dream which came true, merely from the wish to add to the beauties of the World Capital, and while its cost was great even for its present uses, similar beauty may be attained in our smaller utilitarian structures without appreciable extra cost.

The transmission lines from our great electric power plants are carried scores of miles from the source of power directly

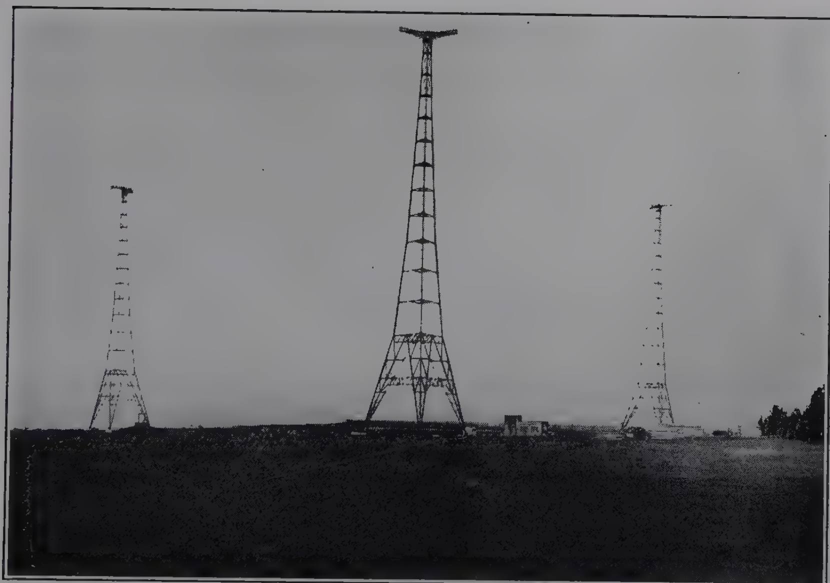
Pearl Harbor Mooring Mast



Lakehurst Mooring Mast

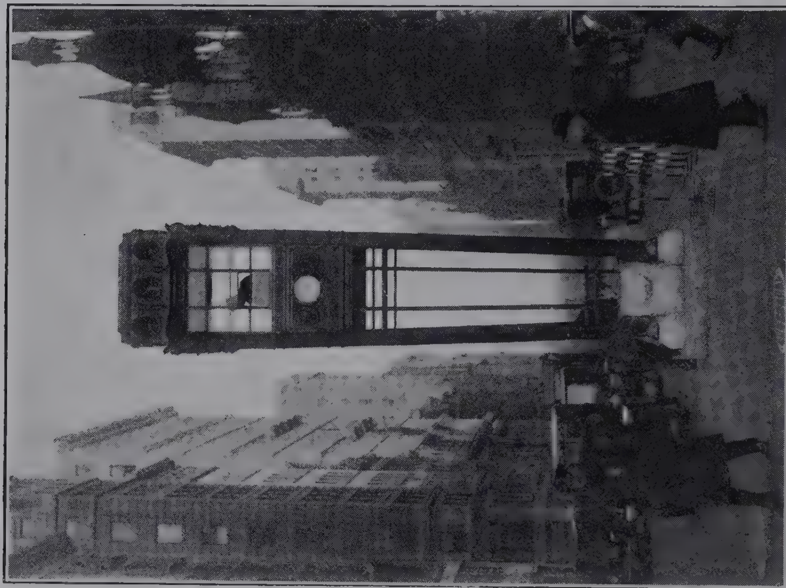
Wireless Towers Alexandria Va.

across the country to the point of consumption, on steel towers of varying heights, and seldom with any artistic efforts having been expended in their design, even for the quite lofty ones which support the wires for long spans over the water. The type shown with straight battered corner posts and ordinary cross bracing, is the one which is almost universally employed, and as if such a structure were not bizarre enough, the cross arms are simply structural units without any

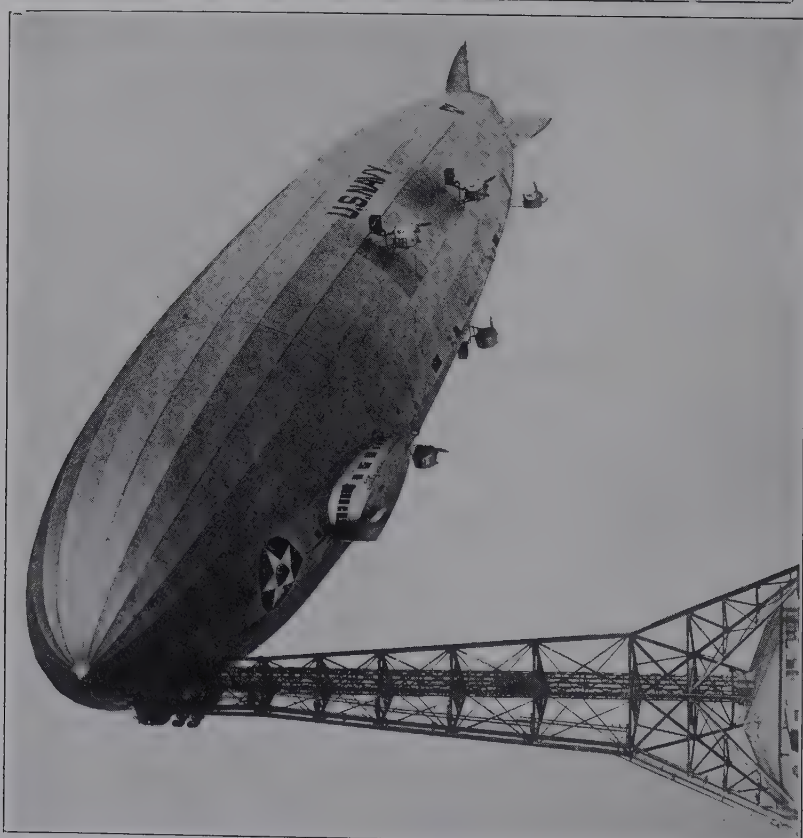


WIRELESS TOWERS MARE ISLAND NAVY YARD

thought having been expended of making them arched brackets of pleasing appearance. The larger tower shown, was used where required, but instead of using some arched portals and vertically curved posts, the angular and unpleasing appearance has been retained. The third design has employed vertical curves, and the appearance has been vastly improved by that feature, and by the curved brackets of the portal bracing. The portals could have been made with full curves, and



Fifth Avenue Traffic Tower



Lakehurst Mooring Mast

the brackets or cross arms of a curved design, so that the entire line of towers would have been insensibly pleasing, if not in reality artistic. The designer evidently discovered that the curves were an element of economy, and it is doubtful if he had any idea of making the towers truly artistic, or else he would have applied graceful curves to all units of the construction. The engineer will doubtless think the design of such towers is of minor importance, and that they are negligible factors in a general movement of artistic uplift, but it

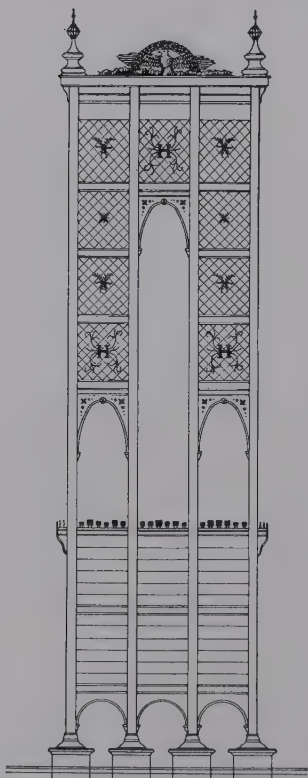
STREET LAMPS

AIRWAY BEACON

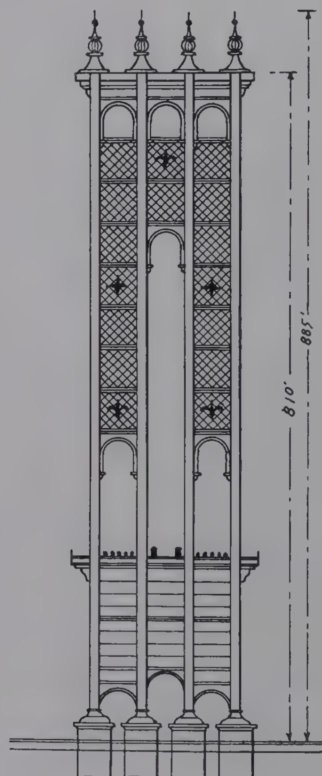
is often the small things which must be remedied if a great aesthetic improvement is to result, and if we are to have a true and comprehensive system of engineering architecture for all classes of structures which come before the engineering designer. The poles for carrying the transmission lines and trolley wires in many of our cities, have always been most unsightly things, and in some cases the wooden poles have been replaced with less obtrusive pipe poles. These too are not pleasing, and attempts have been made with much success,

to make them artistic by placing upon them ornamental light brackets. The moves toward artistic designs of this sort, indicate the urge for more pleasing engineering structures, and if followed up, will assist materially in a proper development.

The airway beacons which are being constructed all over the world have, up to the present, been of a very utilitarian



NARROWS BRIDGE TOWER
4550 FT. SPAN FOWLER



SUSPENSION BRIDGE TOWER
4850 FT. SPAN FOWLER

character, as is shown in the one illustrated. They are analagous to light houses on the coast, and being such prominent features of the landscape, it is to be hoped that future ones may have full graceful vertical curves, proper cornices, and lanterns which will be artistic finials. The air beacon tower shown on the Air Mail stamps is of very plain design, and the

use of one of more graceful outline would have greatly increased the beauty of the stamp, as well as the respect for those having to do with the construction of the towers and structures of the air mail service. The wireless towers and those for use of broadcasting stations are none of them designed with any regard to their having any artistic appearance whatever, and where they have been erected on high buildings in the cities, they have usually added additional dis-

Brighton England Observation Tower

agreeable features to the views out over the city roofs, which are already covered with tanks, rectangular pent-houses, and numerous other excrescences. The reason for all of these things, is the fact that only a few years ago they were out of sight and out of mind; but the time has certainly come for architects and engineers of all classes to join in an endeavor for the beautification of the works of utility. The traffic towers which have been erected on the streets of our cities

during recent years while of small height, have been very largely of very unpleasing design, but the Fifth Avenue Association of New York City, decided that these ought to be works of art on America's most aristocratic shopping street, and on a competitive basis the present design was adopted, so that now these towers are things of beauty, calling out the admiration of all beholders. The expense of such towers was comparatively great, too great probably for "Main Street," but designs may be made of much less cost for their construction, which will be more pleasing than the mere frames which are now in use in so many cities.

The great wireless towers erected at many points in the world are susceptible of being designed of much artistic merit, and at present they are only impressive by reason of their great height. The cost of building them as real monuments like the Eiffel Tower is admittedly prohibitive, but they can at least be made of graceful outline, so as to be pleasing instead of repulsive. The extra cost of designing the tops of proper proportion and of an artistic form would be a very slight addition to the total outlay, and certainly as monuments of wireless and radio, they should be more sightly and artistically impressive, as was the case of the stone radio tower in Holland already described. Should it be found that the additional expense could not be borne by their use for one purpose alone, they could be used for a variety of purposes, as is now the case with the Eiffel Tower, which as we have seen, was built for a purely ornamental and monumental purpose. Those on the coasts can be used as air beacons, light towers for ships, and meteorological purposes at great advantage both to commerce and scientific uses of various kinds.

The great mooring masts that are being built for the anchoring of mammoth Dirigible Air Ships, are still another class of steel towers, where the exercise of some engineering architecture would not be amiss, and now that the first excitement of their hurried construction has passed, it will be advisable for those having charge of their design to turn their attention to having them at least of graceful outline and pleasing proportions. They are likely to be used also as stations for the landing of passengers, mail, and express matter, so that they must have quarters aloft after the manner of light houses, so the exterior of these must be made an in-

tegral feature of the entire design, and within the base comprised in the sweeping curves of the tower, may be built the ground quarters, depots, and shops of various kinds required in the commercial operation of air ship lines, as the towers will constitute the only usual landings.

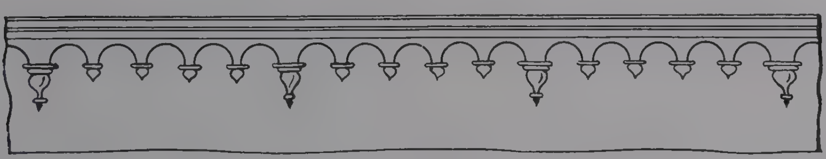
The various other kinds of towers which are required from the designing engineer from time to time, must all be treated as indicated in the foregoing pages, and it should be the part of the engineer to convince those in authority as to the need for the construction of beautiful towers, as well as for utility alone. The future builders should discover that the extra cost is so slight as to be almost ignored, just as the owner of a tall building now disregards the cost of the architectural embellishment of the structure, having come to know that it is the proper thing to do, and that the extra cost returns dividends in no indirect manner. The need for dwelling on these matters is due to the fact that nowhere else has engineering design been so much the purveyor of unsightly structures, and to the further fact that here one can look only to engineers for a betterment of existing conditions.

James Bay Sea Wall Victoria B. C.

CHAPTER XII.

RETAINING WALLS, DAMS, AND TUNNEL PORTALS.

The design of retaining walls has seldom been carried beyond their mere utilitarian planning in a scientific manner to retain a fill or embankment, and only occasionally has any attention been paid to even a neat design for copings, having supporting corbel courses of molded detail or ornamented with dentils. The reason for this is that such walls are usually not visible from a roadway or any near point of view, but even in such locations they should at least be of neat finish, and where they are in full view, they should at any



CREST OF RETAINING WALL FOWLER

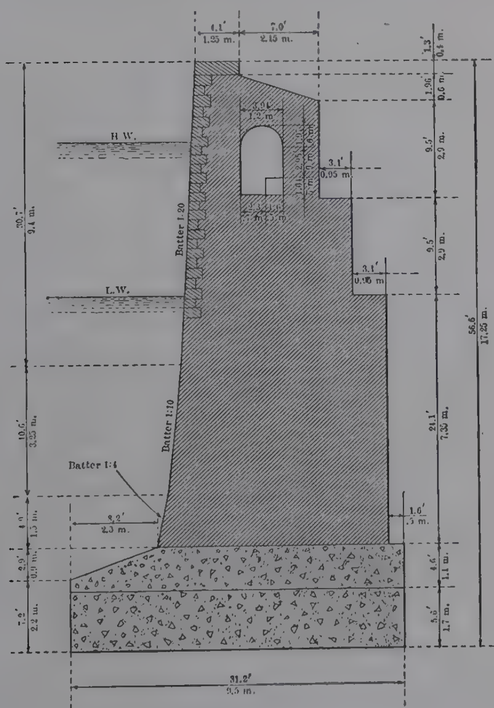
rate have finish or ornamentation of a simple and chaste character. The outlined design shown is suggestive of what can be done when it is possible to expend a reasonable sum for artistic appearance.

The design of sea walls, which are a special type of retaining wall, very frequently affords greater opportunity for artistic planning, and where it extends only to the pleasing concave face of the new Antwerp sea wall, which represents the application only of a pleasing scientific detail, that might easily have been elaborated into a most effective piece of engineering architecture. The San Francisco sea wall at North Beach, designed by M. M. O'Shaughnessy, City Engineer, is an outstanding example of such a structure which is designed in

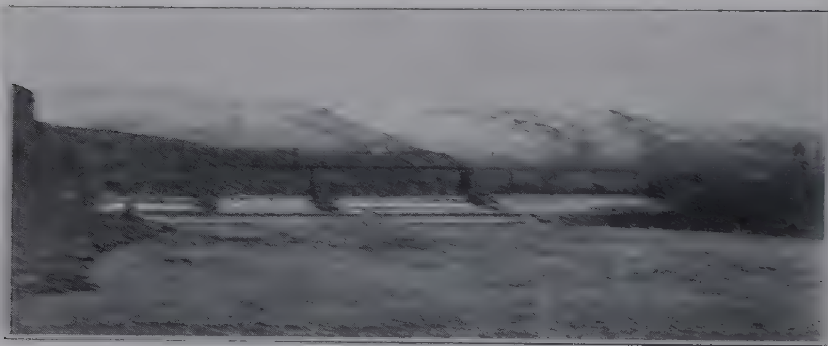
San Francisco Sea Wall

a pleasing and artistic manner, and is primarily planned to withstand the heavy seas which break upon the shore at this location. This Esplanade is described in the transactions of the American Society of Civil Engineers. "One of the most popular sections of the system of boulevards of San Francisco is that which skirts the ocean along the westerly boundary of the city for more than three miles. This boulevard has a

traffic width of 150 feet, and is connected on the north with Point Lobos Boulevard which passes the well-known Cliff House and Seal Rocks. The condition of the beach prior to the construction of the Esplanade was very rough. The problem of protecting this boulevard, known as the Great Highway, had been attempted from time to time, but each method adopted eventually failed, due to the underwashing action of the sea. The ultimate result of this action was apparent—the Great Highway was doomed to annihilation. It became the task to design and construct a barrier that would act as a permanent protection, and that architecturally would add to, rather than detract from, the general beauty of the ocean front, and also cause no marked inconvenience to the crowds that frequent this locality. The Great Highway is 16.5 feet above extreme high tide. The beach slopes gradually upward, terminating in a 12 foot embankment at the westerly edge of the highway. Ordinary high tide brought the sea to the foot of this embankment, and, during extra high tides and storms, giant breakers dashed against it, at times flooding the highway. The problem was to protect the highway and its embankment from the destructive action of the sea, and also to prevent the sea water either in the form of waves or spray, from injuring the highway or its bordering sidewalks. Sand is the only foundation available for form of protection. It extends to a depth of 200 feet beneath the roadway, and is per-



Antwerp Sea Wall



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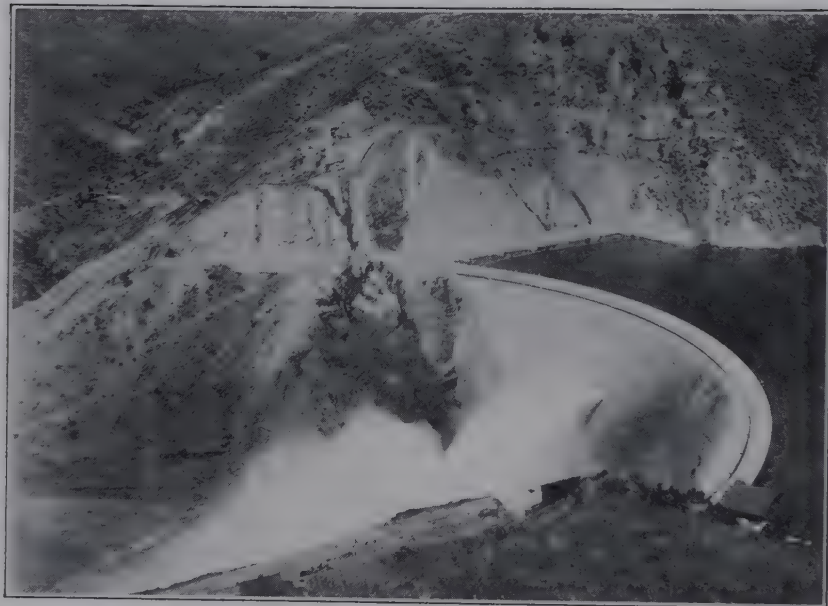
vious and unstable, except where it has been or may be confined. The problem, therefore, was to build a structure that, at all times and under all probable conditions, would resist the direct action of the sea, one fullfilling all conditions. Instead of building a straight vertical wall which would receive the direct force of the water, the wall was divided into a series of steps which sloped upward to the same elevation as would be required for adequate protection by a vertical wall. Each low wall or step receives the direct blows of the waves and

Roosevelt Dam Arizona

causes an abrupt stopping or turning action, and by the formation of eddies and air pockets, dissipates their force. The reaction from the force of the waves on the wall is resisted by a solidly compacted and confined foundation. Thus, the sea itself is used to produce structural stability. The rollway shape at the highest point of the wall is for turning very high waves, and is amply reinforced to accomplish this. The horizontal force exerted against the rollway, tending to overturn the structure, is resisted both by the weight of the superimposed water and by the structure itself." The sea wall at



Arrow Rock Dam Idaho

East Park Dam California

Longport, New Jersey, is designed in a somewhat similar manner, except the outward curve at the top of the wall is much greater, so as to throw back the spray, after the force of the waves is broken by the bottom steps.

The design of dams is of a very similar character to retaining walls, except that for very high gravity dams the sections are made much greater to withstand the enormous water pressures. The upstream faces are often curved ver-

Elephant Butte Dam Texas

tically, but the greatest curve is on the down stream face, which is a fundamental element of beauty. and when the dam is arched horizontally, the artistic appearance is still more enhanced. The multiple arched dams and those of the arched dome type are susceptible of very artistic treatment, but as is the case with gravity dams, they are rarely ornamented in any way, on account of their being located in the mountains where they are not frequently seen. The design of smaller dams which are usually of the overflow type, offers little in the way of opportunity for artistic embellishment, although the ogee

Barrage du Nile Egypt

Portland Oregon Dams

face of the Green River dam, built by the author, makes it somewhat pleasing in appearance, while there was no opportunity for any real embellishment. The author's Chanoine wicket dam over the Yakima river was another case where no money was available for artistic treatment, although the operating bridge afforded a splendid opportunity.

The Vrywny Dam of the Liverpool water system in Great Britain, is not such a high one as are many of the great mountain dams, but much attention was given to its artistic design

VRYWNY DAM LIVERPOOL

and it was so constructed without adding materially to the cost. The dam proper has a sloping face, with the sluiceways of cut stone work, carried above and consisting of a series of beautiful arched openings, very much like a long stone viaduct. The heavy abutment with gate houses in the central portion gives it a very monumental appearance. The arch stones fill the spandrels as well as the arch ring, while the parapet is very well designed and in perfect harmony with the entire structure. The tower which is some distance from the crest of the dam, has already been described. The Barrage du Nile, across the Nile Delta in Egypt, is another dam of the same

O'Shaughnessy Hetch Hetchy Yosemite Dam

type as that at Liverpool, and carries a roadway on top of the arches of the sluiceway. The towers are very oriental in appearance, with beautiful battlemented tops. The masonry is of brickwork, with stone arch rings, stone quoins, and stone trim throughout. The effect of the entire construction is very monumental, and the Barrage may be classed with the best examples of engineering architecture.

The great gravity dams are of the type of the O'Shaughnessy Dam of the San Francisco water system. It is located in the Yosemite, and has a maximum height of 344.5 feet, with a length of 605 feet.

The dam was designed and built by M. M. O'Shaughnessy, M. Am. Soc. S. C., City Engineer of San Francisco, as the most important feature of the new water supply for the City, and for future increase the dam will be raised to a height of 430

Multiple Arch Dam Fowler

feet, with the base width of 298 feet, and 25 feet 9 inches on top, thus making the highest dam in the world. The arched gravity type with a 700 feet radius, is very pleasing in appearance, and the steps in the exposed face of the dam add to its very striking appearance, although they are to serve as a bonding factor when the thickness is increased to allow for the added height. The simple yet beautiful parapet which protects the roadway across the crest and the central plaza, makes a very satisfactory finish for the crest. The smooth finish is due to the use of cyclopean concrete in which large blocks or stone were imbedded, ranging from one cubic foot to five or six cubic yards in size. Altogether the structure is the most remarkable one of its kind in the world, where simplicity has been the keynote to beauty, and to harmony with the mountain masses.

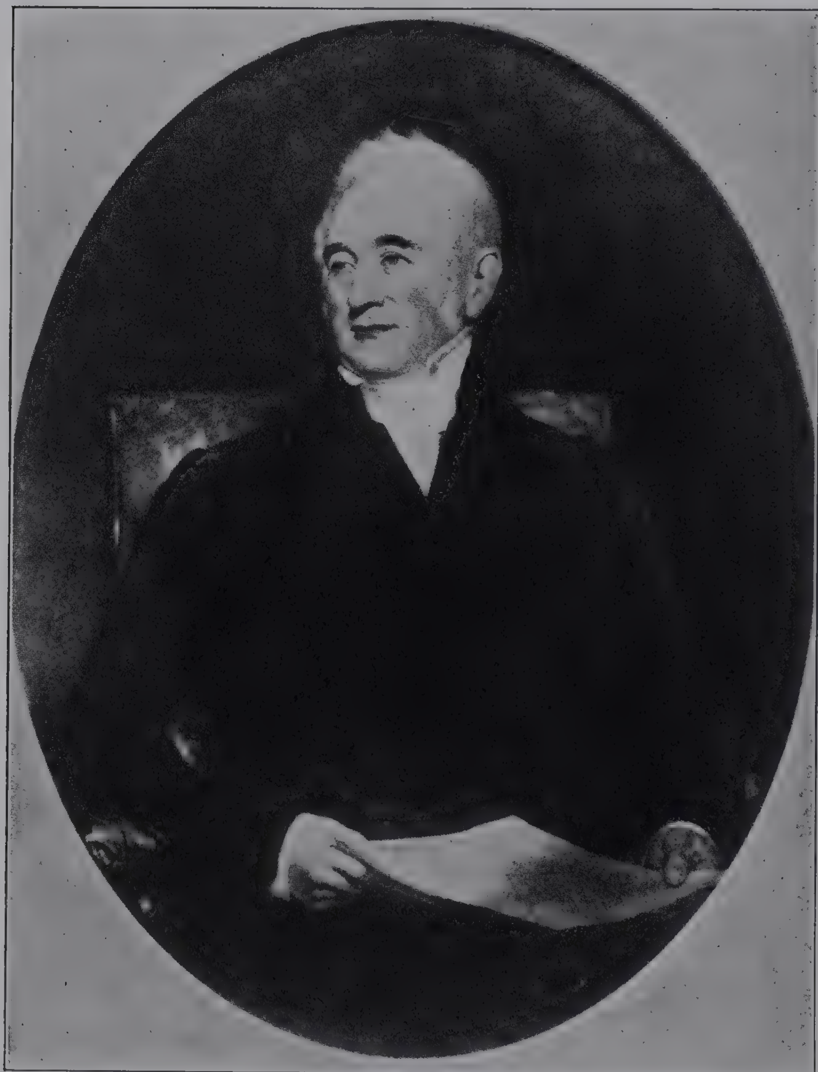
The Roosevelt Dam in Arizona is one of the largest in the world, being 280 feet high, 1080 feet long, and having a base

Croton Dam New York City Water Supply

158 feet wide. It is curved in plan with a radius of 400 feet, and has a curved face down stream, so that basically it is very pleasing in appearance. The ornamental pilastered crest is also very nicely detailed, and illustrates what a small additional cost is necessary to add some artistic features.

The Arrow Rock dam in Idaho is 349 feet high, 1100 feet long on the crest, giving a reservoir capacity of 280,000 acre feet, at a cost of nearly $4,250,000. The structure is curved in plan, with no decoration except a coping and low parapet, but the harmony with its surroundings is very apparent. The great Elephant Butte dam on Rio Grande project, is 306 feet at its greatest height and is 1675 feet long on the crest. The reservoir capacity is 2,638,000 acre feet, and the cost slightly over $4,500,000. The decoration of the top of the dam approaches very nearly the author's idea of an appropriate and pleasing design, and had every fifth pilaster been carried farther down on the face, the slight monotony would have been broken. The East Park dam in California is a small one of only 139 feet height, and has a crest length of 250 feet. The slight curve, the finish of the crest, and the rugged scenery make a very pleasing ensemble.

The concrete dams for the city reservoirs on Portland Heights at Portland, Oregon, have been detailed in a very artistic manner, and while the arched effect at the crest is well proportioned, had the arches been divided into groups of three or five by pilasters or even with long pendants, as shown for retaining walls, the result would have been much more pleasing. The dentiled corbel course is very appropriate to the design and well proportioned. The balustrade is of very good design, and well illustrates the beauty of extreme simplicity. The gate houses are in entire harmony with the design of the dams, and much more appropriate than would have been ones with a classic motif. The structures are in full view from the park drives and walks, so that the cost for their ornamentation may be considered as having been well expended. The new Croton Dam of the New York City water works is one of the finest and most monumental masonry structures in the world, with a length of 1200 feet, a height of 238 feet, and a width of 185 feet. The great curved face is broken by the end abutments and the three intermediate buttresses. The steel arch bridge over the spillway is of good design and adds



George Stephenson

materially to the artistic effect of the structure. The crest of the dam is most artistically treated for the center or high section, with thirty-five flat arched dentils with pendants, above which is a parapet of very chaste design with ordinary dentils. Had the arched dentils been broken up into seven groups of five each, either by longer pendants or by pilasters, the artistic appearance would have been much enhanced.

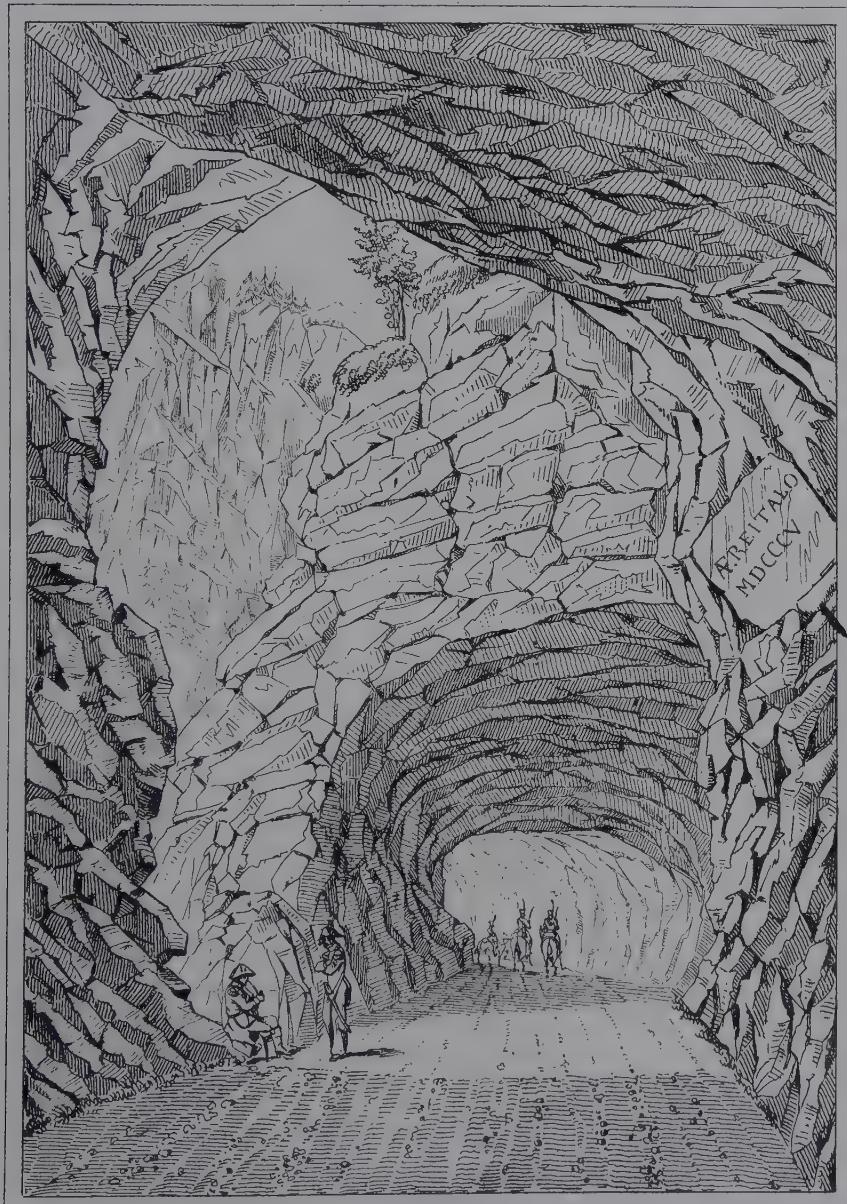
This feature is shown in the outline sketch, and while the author believes it to be a much better design, it would also have given the effect of greater height and have relieved any flatness of appearance.

The multiple arched dam is of a type which is susceptible of the very best architectural effect, but so far none of those built have had anything added of a specially artistic nature. The Gem multiple arch dam in Mono County, California, has a height of 112 feet, and sixteen complete arches in a length of 688 feet. Had there been fifteen arches in groups of five, with half dome tops supporting a well proportioned parapet, the dam would have been quite artistic in appearance. With end abutments and two intermediate buttresses separating the groups, the effect would have been still further enhanced, as is shown by the author's sketch. The details of such ornamentation need not be of an elaborate character, as simplicity would be in harmony with the surroundings.

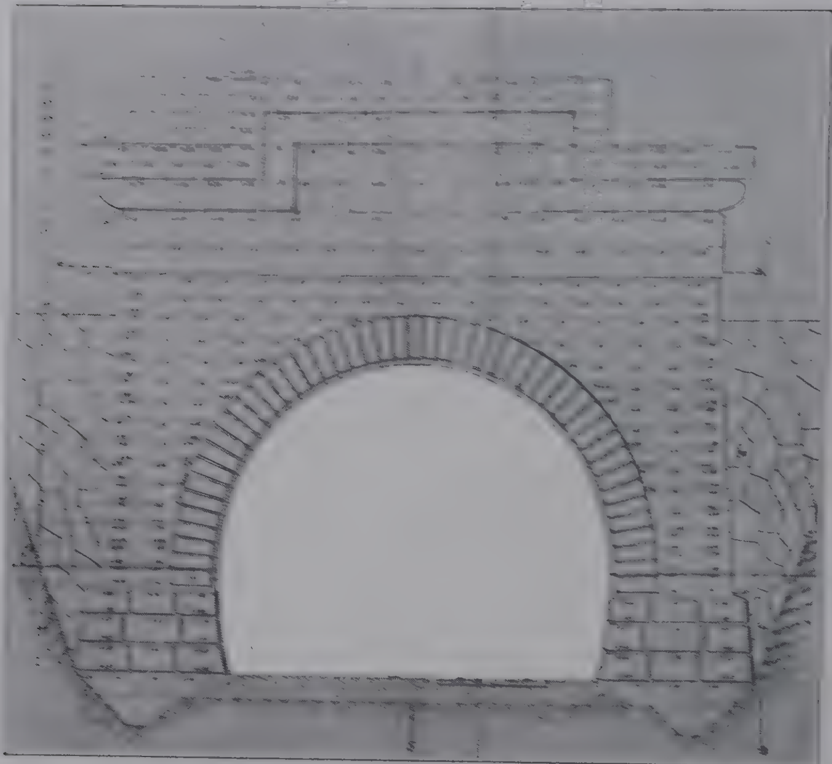
The design of tunnel portals is usually of the crudest character, and where they are on railway lines, with only a fleeting view possible from the observation platform of a train, this may be somewhat excusable. Yet even in such locations there is no excuse for any design which is not of a neat, monumental, and pleasing character. The portals of the great Moffat Tunnel in the Rocky Mountains are certainly an outstanding example of what not to do, and a reflection upon the taste of engineers. The difference in cost would have been next to nothing, as between a pleasing monumental design, and the very crude one employed. The use of a very simple design for the portals of a tunnel on the Russian Railways is shown, to illustrate how easy it would have been to have avoided the angular and displeasing ones that have been built, and which stand forth as representing a crudeness in American engineering which should not exist.

Simplon Tunnel Portal Italy

Armstrong Tunnel Portal Pittsburgh



Gallery on Napoleon's Simplon Road



[illegible] Tunnel [illegible]

[illegible] Tunnel, Great Northern Ry.

The Alpine tunnels have very neat and pleasing portals, as a rule, and those for the Arlberg tunnel in Austria are of very artistic design. While this tunnel is only 4.4 miles in length, it is on an important railway line, and in a location where it can be readily seen and its pleasing appearance fully appreciated. The Simplon Tunnel which runs under the Simplon Pass from France to Italy is 12.4 miles in length, 16.4 feet wide in each bore, with a height of 18 feet. It was begun in 1895 and completed in 1906 at a cost of $240.00 per lineal foot. The maximum depth below the surface is 9118 feet, and it was lined with coursed masonry. The portal shown in the view is that at Iselle, Italy, and the other one is at Brigue, Switzerland. The portals are of very simple and neat design, and are models of what should be done under similar circumstances, as their cost is a mere fraction of one per cent of the cost of such a great undertaking. The Simplon highway over the Alps was constructed by Napoleon, and the short tunnels or galleries serve to accentuate the progress of over a century in travel, when the railway double track tunnel 12.45 miles long is considered in comparison. The new Cascade tunnel on the Great Northern Railway is 7.79 miles long and the fifth longest in the world. The concrete portals have the one merit of extreme simplicity, where there was a splendid chance for monumental ones, which may be added later. The portals of the Armstrong Vehicular tunnel in Pittsburgh are of very neat design and their simplicity is in full keeping with the location and purpose. The masonry is of the best character, and the arch rings of the two arched openings very artistically designed and detailed. The wing walls are stepped in good proportion and very simply and neatly capped. Not less pleasing is the more elaborate coping over the portal, which carries the name, while the dentiled corbel course adds to the effect, which is very harmonious and pleasing.

Power House Perpendicular Design

Niagara Falls Upper Power House

CHAPTER XIII.

DESIGN OF POWER HOUSES.

The design of power houses and shop buildings for Utilities must of necessity be the work of engineers, as they must make all the ground and floor plans for placing the machinery, design the foundation, the floors, the traveling cranes, the steel roof and covering, the supporting columns, and decide whether the walls shall be monolithic concrete or of the curtain type of tile or brick. The only matter then left for decision is the style or decoration of the exterior, and too often this has resulted in the use of only plain walls, of no architectural pretentions whatever, like the one illustrated, as built for a California power plant. Such a building serves the purposes of the plant and being in a remote mountain canyon, it is seldom seen by any one except the employees of the company, but it in no way contributes to their morale or to make their employment of a pleasing or edifying character.

The arrangement of the floor or floors must be such as to best accommodate the turbines and dynamos, so these plans must be decided upon by the electrical engineers. The foundations usually go down to rock, and thus no serious problem is often presented from this source, but if rock is deep down, then special foundations are required, which may demand the services of an expert in this branch of engineering. The machinery is usually of neat and graceful design, so that the structural engineer should design the steel work to contribute to a pleasing and graceful interior, thus curved brackets may be used for crane runway bracing, and arch roof trusses may be employed with good effect and little increase in cost. The posts for carrying the crane runways may be made a part of the main roof columns so as to produce a pilaster effect along the interior of the walls. The exterior of the walls may be made artistic by using pilasters, or high arched panels over the windows, and by having a neat and well proportioned cornice. Some such design is the least that should be done,

Power House Sierra Madre Mountains

La Gabelle Power House Canada

but much more might be spent to advantage in additional and harmonious decorations both of the interior and exterior. The perpendicular style which has been used in the English building illustrated, is of a type which while very simple, is yet very pleasing in appearance.

The buildings of the Ontario Hydro Electric plants at Niagara, are very well designed, and the one at the Falls is a very striking piece of architecture, while the office and head building at Queenston is plainer in design, but very harmoni-

QUEENSTON NIAGARA LOWER POWER HOUSE

ous for the purpose, as well as pleasing in appearance. Everything about all the plants is kept in such fine condition that much is added to the artistic effect by the mere element of neatness.

The dam at La Gabelle on the St. Maurice in Canada is very plain and unpleasing, but the monumental power house is of a very neat and appropriate design, forming part of the dam and resting on the original bed of the river. The details are all of a most simple character, such as could easily be

QUEENSTON POWER HOUSE NIAGARA

planned by the Engineer. The plant is part of the Shawinigan system, and the dam floods out the La Gabelle Rapids and Les Gres Falls for a distance of one mile, giving an operating head of only 65 feet. Yet the power developed is 120,000 horse power with 30,000 more to follow, and forms one of three units in a 13 mile stretch of the St. Maurice River, which will have a total of 507,500 horse power. The plant at Smoky Falls on the Mattagami River in Ontario has a building of very pleasing character with high arched panels about the windows and a good cornice, as previously suggested. This project comprises a pulp and paper mill at Kapuskasing having a combined capacity of 600 tons daily, a power development of 75,000 H. P. at Smoky Falls, on the Mattagami

POWER HOUSE MATTAGAMI RIVER

River, and 50 miles of transmission line between Kapuskasing and Smoky Falls, the whole linked to the Canadian National Railway system by 50 miles of standard-gauge railway. The power structures at Smoky Falls are all of solid concrete construction. In the main dam ten 40-ft. Stoney sluice-gates are provided to take care of the spring run-off. In its final form the power house will contain four units of 18,750 H. P. each. At present three units are being installed and one is running. Smoky Falls provides a natural head of 78 ft., which has been increased to 114 ft. The natural formation at Smoky Falls made an ideal site for a power development. An island divides the river into a gorge that is almost a ready-made tailrace and a wide and comparatively shallow series of rapids.

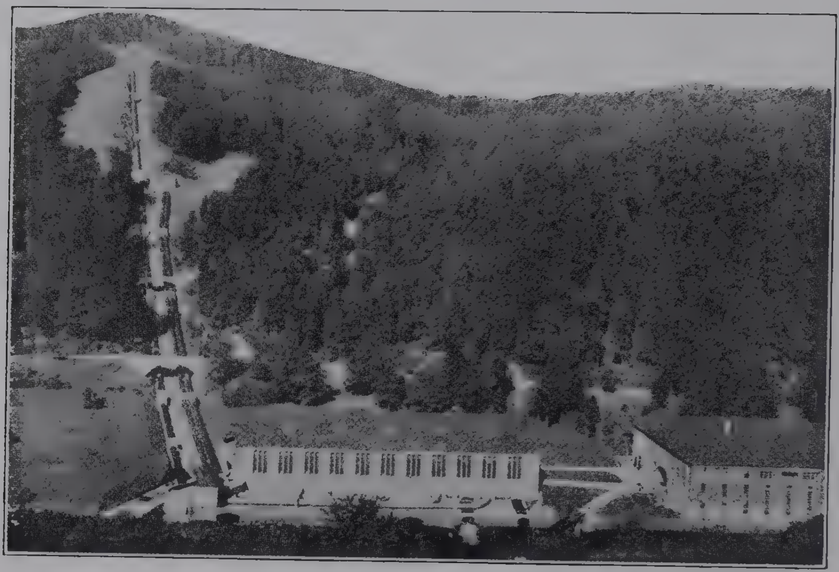
Ferdinand De Lesseps

The banks of the river are sufficiently high to give a large water storage. A steel flume 17 ft. in diameter brings the water from the forebay at the head of the gorge to the power house below. The towers for the 50-mile transmission line are 80 ft. high, spaced 800 ft. apart, and carry two aluminum circuits for transmission at 110,000 volts.

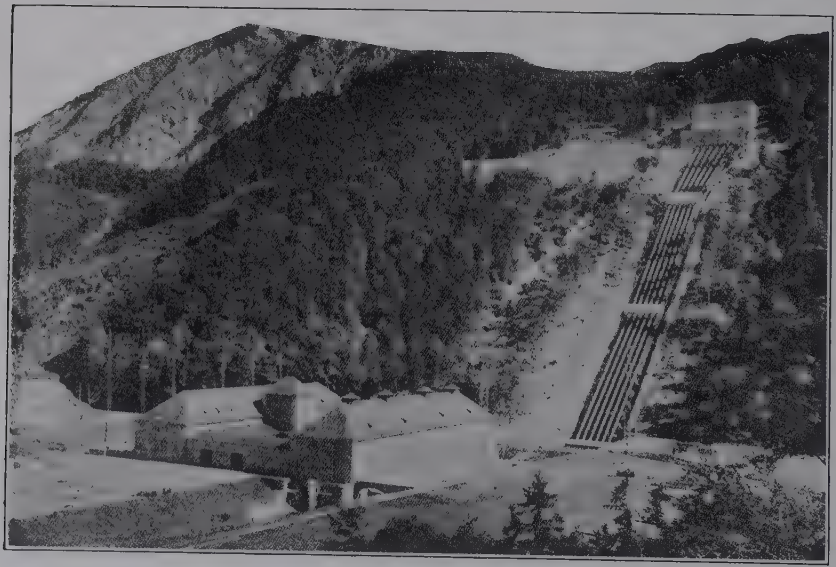
The power house at Conowingo Dam in Pennsylvania is another one of much the same type as the one in Ontario just described, and both of them could have been improved in appearance at a very small additional expense. The European plants are many of them provided with power houses which

Conowingo Power House

are supposed to be works of architecture, but do not in the author's opinion compare favorably with many of those in America. The buildings of the Baden Utility Company in the Black Forest are impressive, but not of anything more than neat design, although the arch bridges above add a little of grace to the view. The buildings at the Walchen Lake plant in Bavaria are also simply huge masses with no particular style. The head house is better detailed and very striking, but not one to enthuse about. The principal reason for illustrating this plant, is to show the transmission towers, where curved portals or bracing give a very pleasing effect.



Murg Plant Black Forest



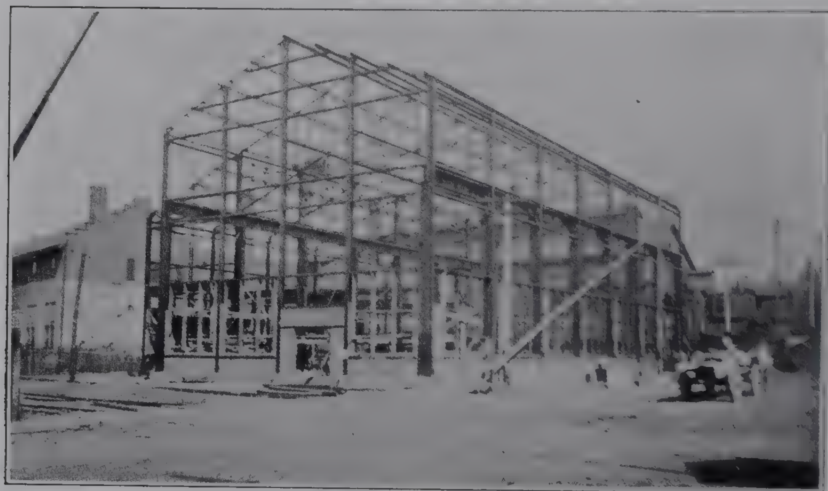
Walchen Lake Bavaria

The steam power plants scattered over the country are most of them merely monumental in appearance, like the small one at San Antonio, Texas, and it is difficult to understand why the pleasing detail of the arch in the parapet was not repeated to an artistic advantage. The smoke stack adds to the pleasing appearance, but is counterbalanced by the unsightly constructions on the roof. The smaller power buildings in the cities, are usually very much more artistically designed, as is seen from the one for a sub-station in Wheaton, Illinois, which immediately suggests the Southern California Mission style, and might well trade places with the Receiving Station in Los Angeles. This is merely a neat, simple,

Los Angeles Sub-station

and chaste design, and the Doric pilasters at the entrance are not so inappropriate as they might be for some other engineering structure, as they harmonize well with the ensemble of the building.

The shops connected with the power plants are usually of no particular note, except that they have been designed for the greatest efficiency and utility. Very often they are monolithic concrete structures, with steel beams or girders to support the roof covering, and are no more sightly than the power house referred to at the beginning of this chapter. The design of steel frame buildings of one story has become very much



Modern Machine Shop Design Fowler

Modern Machine Shop Exterior Fowler

standardized, and the steelwork often made no heavier than is required to carry the loads safely. The moisture around all power plants is conducive to rusting of the steelwork, if the upkeep is not the best, and in steam plants, blacksmith shops, and other similar buildings, there are gases to reckon with, so it has always been the author's practice to increase the thickness of the metal from ten to twenty-five per cent, as judg-

Toll House Hutcheson Bridge

ment dictates, so that any deterioration will be fully anticipated, and no future trouble ensue.

The heavier type of steel frame buildings is usually made the subject of special design, as was the case for the machine shop, shown before the wall and roofing were placed, and also afterwards when the building was finished. The steelwork was of quite heavy sections, and well braced with sway rods, as well as much stiffened by the crane runway girders. The

main columns were designed of plate girder section, with an offset to form the seats for the heavy crane girders, and a smaller section above to carry the steel trusses and roof. The purlins were of channels which are an economical section for the purpose, much stiffer in general and more lasting. The sides were enclosed with brick curtain walls with no relief or decorations, except a steel end and side cornice of modest proportions. Very slight additional expense would have been required to have given a pilaster and arched panel relief to the sides, and to have provided a more adequate cornice. The use of rock faced tile blocks for the side walls is a very effective method of adding to the pleasing effect of

San Antonio Texas

Wheaton Illinois

such structures, and all such types may be fully designed by the engineer, so it is to be hoped that in many instances they may be so planned as to become additions to our engineering architecture.

The buildings necessary for the offices, toll or gate houses, keeper's lodges, and like purposes in connection with bridges, are all of a simple character, and should always be designed by the engineer, so as to fulfill all conditions and be in full harmony with the structure. They may be of concrete with steel floor beams and steel roof, or they may be steel frames with curtain walls, and in some cases all steel, stamped metal, and glass. Toll houses of this latter type were designed by the author for a large International Bridge, and with the arched

and graceful sides, and rounded ends, they were not too elaborate, but of neat enough design to harmonize with the bridge, and afford the necessary room for all the employees on duty at one time. Another case was where more substantial buildings were required, so the design was made for concrete buildings of simple classic design, and with each office and toll house under the same roof, which was extended to

TOLL HOUSE DESIGN FOWLER

form a porte cochere over the roadway. The use of a classic motif may be excused for a building, but it is not a necessity in carrying out the fundamental principles of a system of engineering architecture, and an attempt should be made to develop a design with an explanatory motif, as was the case with the Einstein Tower, and also for the Holland Radio Station, but it is better to have all parts of a project in harmony, than to have some portions of such novelty as to mark their isolation.

Connecticut Avenue Bridge Entrance

CHAPTER XIV.

APPLICATION OF ORNAMENT.

The preceding chapters have covered many of the features of the ornamentation of engineering structures, especially in the paragraphs criticizing the details of existing structures. Therefore by elimination the designer must avoid the bad features, and to a great extent be guided by the details of

Fergus Falls Minn. Balustrade

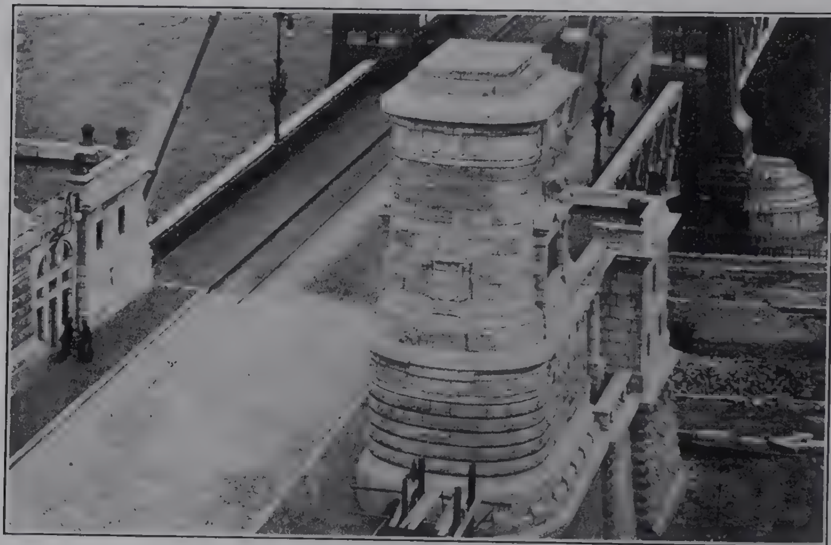
structures already built in designing the decorative details of new designs, even to the extent of originating many new ones to harmonize with special types of construction, just as architects have been forced to do, in clothing the steel skeletons of high buildings. The outright use of classical details must be

MICHELANGELO

avoided in the great majority of cases, but when necessary to use them to make a structure harmonize with the environment, they must be incorporated in designs with the greatest of caution. This does not of course apply so directly to the use of architectural proportions and the application of minor ornament, which are usually necessary to be used in the design of many engineering works to make them artistic, and to have them agree with our established ideas of aesthetic design, which have become fixed in the minds of the artistically educated from hundreds of years usage in all countries.

NILE BRIDGE ENTRANCE CAIRO

The Connecticut Avenue Bridge in Washington, D. C., is a case where the persons crossing do not see the bridge itself, but only the artistic features of the entrance and the balustrades. When approaching the structure, one sees the huge lions guardant and the beautiful light pylons at the entrances, which on closer view are seen to harmonize with the balustrades and the lamps on the bridge proper. The layout of the entrance driveways is conducive to a proper and pleasing view and appreciation of these decorative details. The entrance



Elizabeth Bridge Entrance

Marienburg Bridge Portal

lamps are of exquisite design, very appropriately surmounted by the American eagle, and have well proportioned bases, which proclaim them pylons instead of mere lamp posts. The huge concrete lions are very artistically posed, but would look entirely out of character without the well proportioned pedestals. The double lights are placed on the balustrade over the abutments and end piers, while single lights are placed over the main piers, and all are of the same beautiful design. The parapet balustrade of the Fergus Falls, Minn., bridge is also

Hammersmith Bridge Entrance

of very artistic design, and had there been correspondingly appropriate entrances, it would have been in every respect a very pleasing finish for a small structure. The heavier lamp columns are very harmonious, and not too heavy to be carried by the solid panels of the balustrade. The very simple design of the open work dado of the balustrade is nevertheless very artistic, harmonious and pleasing. The steel bridge at Cairo, Egypt, the Pont du Nile, is merely a riveted lattice structure of no architectural pretensions, and yet it has been given a

Bushnell Park Memorial Arch

Manhattan Bridge Entrance

monumental appearance by the very simple expedient of placing monumental pylons at the entrances. The great lions are placed on pedestals, which are much more finely detailed than those just described, with carefully detailed bases and battered shaft, surmounted by a finely molded cornice, which carries the seat for the figures.

Brooklyn Bridge Proposed Entrance

The pylons at the entrances to the Elizabeth bridge at Budapesht are of an entirely different type from those of the Connecticut Avenue Bridge, and are in reality a finish for the anchorages. The base mold is carefully detailed with joggled dentils, carrying a quarry faced dado, with cut stone molded capping. Above this is the shaft of cut stone carrying shields

Washington Bridge Approach

St. Louis Bridge Approach

and ornamentation, all surmounted with an exquisitely designed cornice and capping. These join directly to the gate houses of the same height as the bases of the pylons. The only criticism to offer, is that they are somewhat too massive in appearance for the suspension bridge, with its proportionately lighter towers. The entrances to the old Tierney Clark bridge not far away, are of much simpler design, but are in better harmony with the stone towers, which have been previously described. The design of the gate houses is somewhat

Roman Bridge of St. Chamas

classic, and they are placed at the extreme of the entrances, while lions on pedestals are located inside of these and over the anchorage.

The decoration of some of the stone arch bridges of the Romans, was effected by the erection of triumphal towers at the ends, as was done in the case of the bridge at St. Chamas, which was a short span of no artistic pretentions whatever, except the mere circular curve of the arch. The monumental arches at the ends however, are very elaborately designed, with a well proportioned arch over the roadway, and an entab-

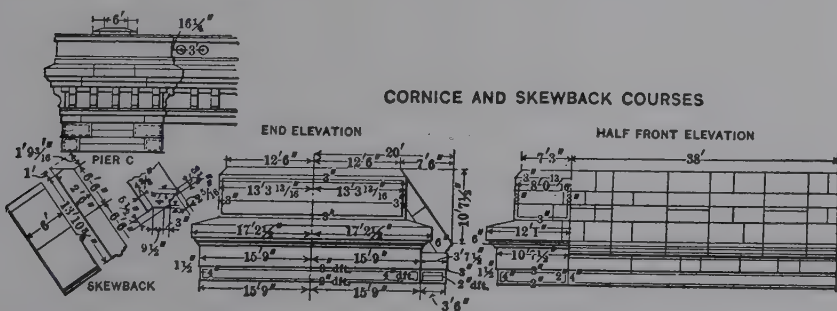
Gate Houses Queensboro Bridge

Tower of Hell Gate Arch Lindenthal

lature carried by classic pilasters at the corners. Over the crown of the arch, on the entablature, was the inscription probably by the Emperor Augustus.

L. DONNIUS. C. FLAVOS. FLAMEN. ROMAE. ET. AUGUSTI. TESTAMENTO. FIERREI. JUSSIT. ARBITRATU. C. DONNEI. VAENAE. ET. CATTEI. RUFFI.

Cresy says, "By this inscription we learn that it was erected according to the will of Donneius Flavos, priest of Rome, and Augustus, under the direction of Donneius Vaeneus and Caffeus Ruffus. But it does not assert that Donneius Flavos was contemporary with Augustus, or which of the emperors of that name is referred to." The entire design does



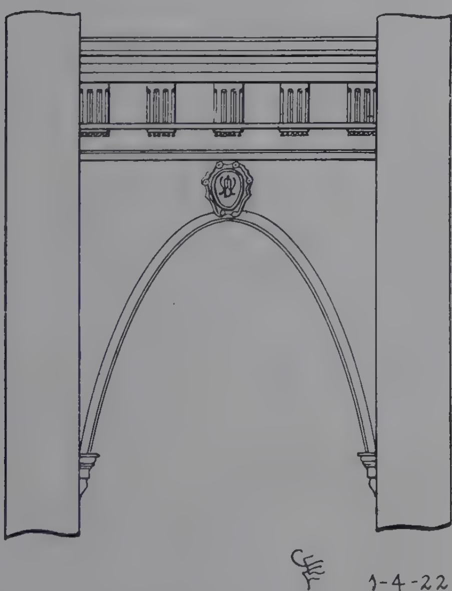
Washington Bridge Masonry Details

however make plain the regard quite frequently of the bridge itself by the Romans, only in their eagerness to find locations for more monuments to herald their glorious Empire and marvelous achievements. The use of such arches became well established, and not infrequently the idea has been adopted at later periods. The stone arch bridge in Bushnell Park, at Hartford, Connecticut, is a five span structure of especially good general design and of good detail, but it is too small to be of much note, as was the case with the bridge proper at St. Chamas. The end of the Hartford Bridge was considered a proper place for the Memorial Arch of mediaeval design and of very fine detail. The two examples demonstrate that the entrance to bridges may be very appropriately chosen for the erection of triumphal or memorial arches, and that they should be made to harmonize with the ensemble of the bridge.

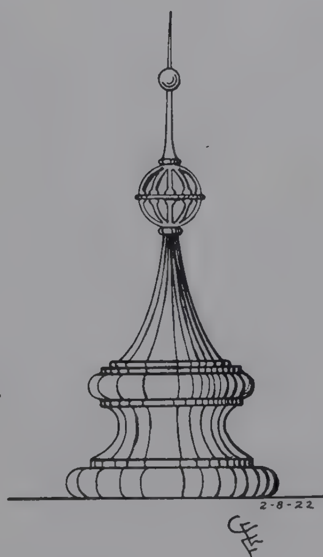
Hell Gate Arch Skewback Lindenthal

Minne Bridge Piers Norway

The matter of detailed ornament for the towers of a suspension bridge, is much harder to decide upon than for many other classes of engineering works, and while the general motif of the towers may be Gothic, Romanesque, or Mediaeval, it is certain that no general or major detail should be lifted from one of these styles and transplanted upon such a tower, any more than classic columns and pediments should be placed upon the piers or abutments of arch bridges. The proportion of the towers may be obtained from some architectural tower;



DETROIT ORIGINAL PORTAL DESIGN FOWLER

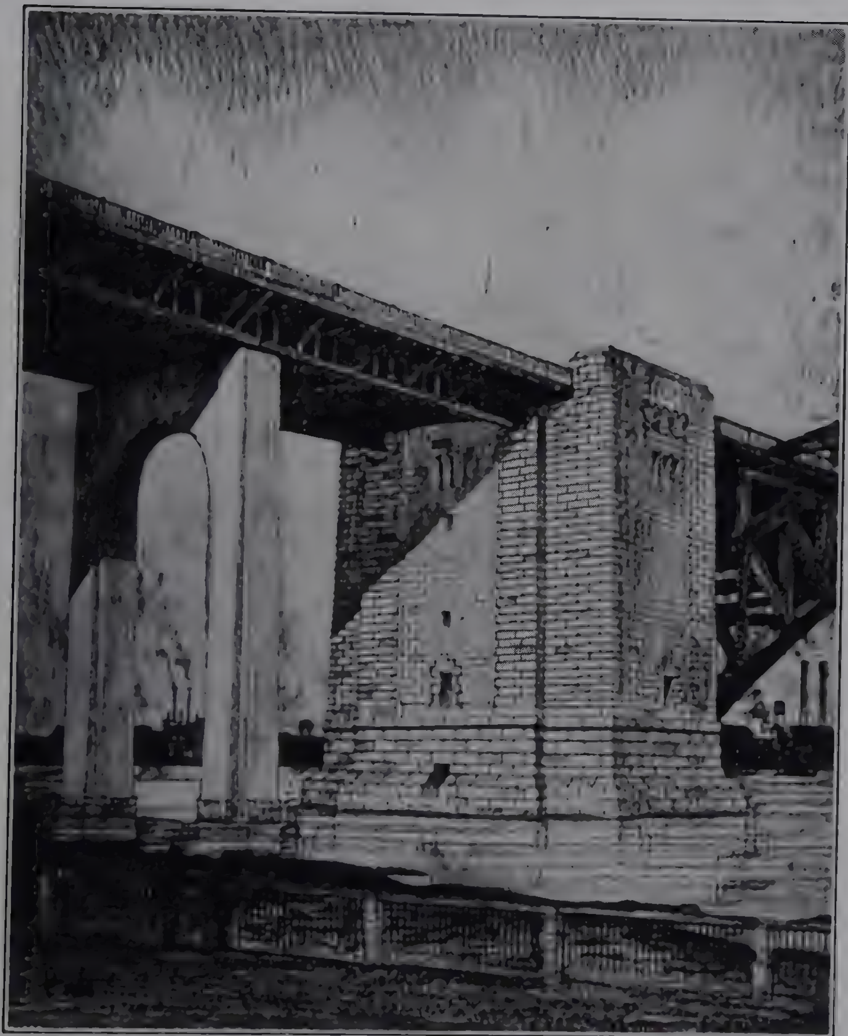


DETROIT FINIAL DESIGN FOWLER

the proportions of the details likewise may be so procured; and minor details may be designed as exact counterparts of really artistic architectural details, without transgressing the bounds of the best basic principles. The original design of the Detroit towers was made by the author, by using the three tiers of three bastard gothic arches having medallions carrying monograms at the crown of each arch, with all the moldings and cornices proportioned from classic models. The ornamentation of the dados of the cross struts, was through the application of triglyphs, and the finials with cressets were

Entrance Alexandre III Bridge

Czernavoda Bridge Pier and Portal



Kill von Kull Arch Abutment

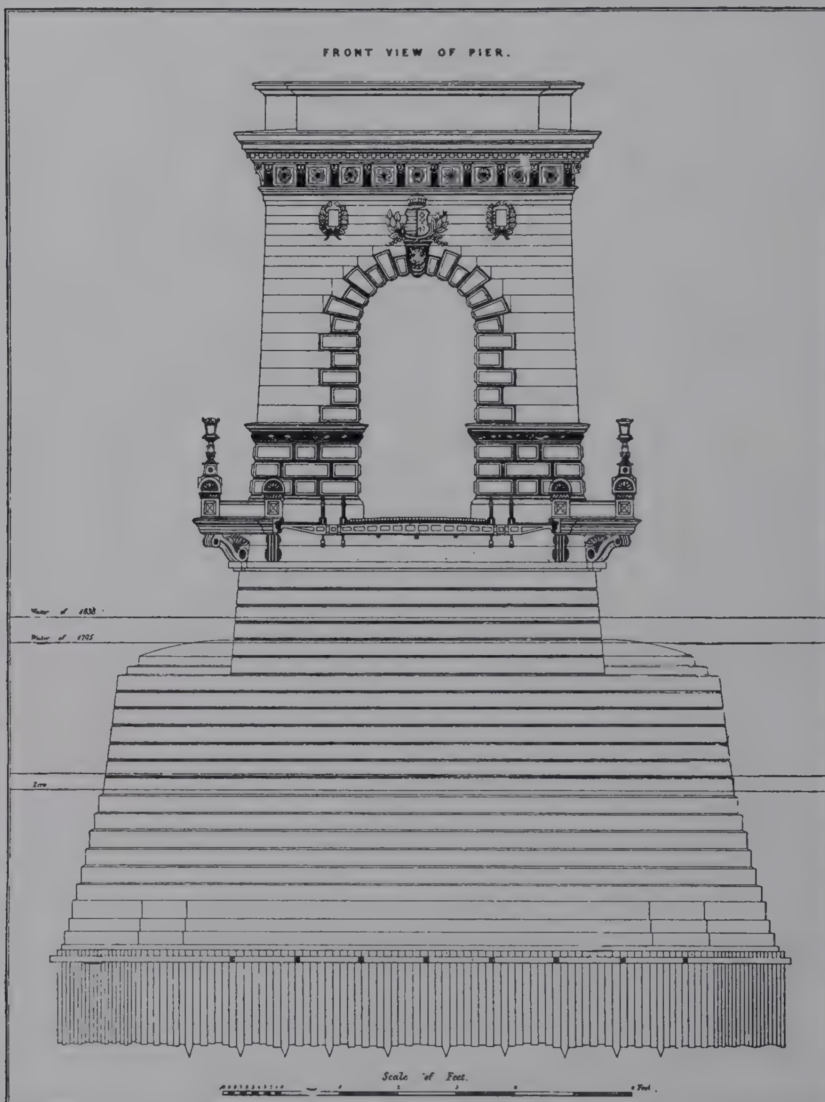
of classic proportions. All of the various parts and details were made to harmonize and of proper proportion for the size of the towers, thus producing a very pleasing, though somewhat hybrid design.

The towers of the 4850 feet suspension bridge already described, were of a Romanesque motif, with double lacing on

Brooklyn Bridge Towers

the faces of the tower posts instead of unpleasing cross bracing. The arrangement of the high arches over the roadway is quite pleasing, and to avoid a top heavy appearance, three comparatively small arched openings were placed at the top. The proportions of all the details were taken from the Roman classic orders, and a very satisfying ensemble was attained. Similar towers designed for a 4550 feet suspension span were Empire Style and naturally followed the artistic trend of that period, which was based on classic architecture. The design was carried out with no use of any classic transplanting of large scale portions, but by using the proportions in an appropriate manner, and using details which were similar to the decorative motifs of the First Empire, which give a neat and pleasing effect. (see Chapter XI)

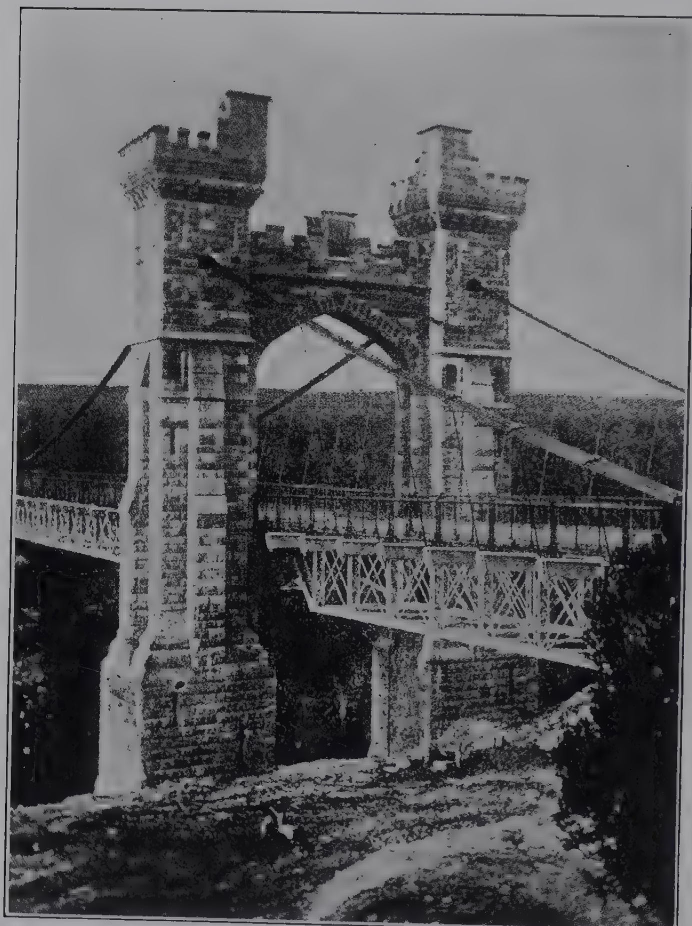
The general design of bridge piers has been referred to in the preceding pages, and many details may be seen in the illustrations of the bridges discussed in the various chapters. The ornamentations used must always be of a simple and chaste character, as anything of a frivolous type would be most inappropriate if applied to such massive portions of a structure as are piers and abutments. Usually the only ornamentation that would be suitable, is the use of finely cut courses, where such curved moldings, as were used on the piers of the Queensboro Bridge in New York City, are in entire harmony with the structure, and with proper finish of all its portions. When it is desirable to carry shafts or pylons above the roadway, it can be accomplished, as was done on the end piers of this great bridge, where a gate house effect was found to be very pleasing. The belt courses, the medallions, the openings, and the capping are of most exquisite detail design so as to make the piers almost works of engineering architecture in themselves, but at the same time in entire harmony with the entire bridge, as well as with the molded bases and tops of all the other piers. The arched openings in the pier shafts, while adding much to the appearance, served to lighten the load on the foundations, and by the great saving in the quantity of masonry, reduced the cost materially, thus proving that ornamentation often reduces the expenditure, instead of increasing the total outlay.



BUDAPESHT SUSPENSION BRIDGE TOWER

The piers of the great Czernavoda Bridge in Roumania, already referred to, are another example of the appropriate detailing of bridge piers. The expense in this case was warranted in the successful attempt to create a truly monumental engineering work, which reflects great credit upon the engineers, constructors, and upon the nation itself. The pier shafts are of the utmost simplicity, with rounded ends, but the arched towers which surmount them are quite ornate in design, and yet not of an obtrusive character. The bases are of cut stone, with molded courses, while the arches are of fine proportions. The dentiled cornices, the cappings, and the beautifully detailed parapets are worthy of much study and emulation whenever it falls to the lot of the engineer to design such monumental work. The use of statues for further ornamentation is open to question, and a matter which must be decided by the designer who is aware of all the exigencies of the case, but they were applied to this bridge in a comparatively unobtrusive and appropriate manner. The decoration of other European bridge piers has in many cases been carried out in a very appropriate manner, as was the case of the piers for the Norwegian bridge at Minne, where the pier shafts are pierced by gothic arches, and are crowned by beautifully dentiled cornices and cappings, so well executed that it is doubtful if the cost was more than is often incurred for much plainer piers.

The decoration of other engineering works should always be carried out with a strict observance of the tenets already enunciated and discussed. The Cordouan lighthouse was of course entirely too ornate for a structure of this class, and yet it was found that the decoration served a purpose in breaking the waves while at the same time being most pleasing in appearance. The one at Isle Vierge is ornate enough to be an outstanding piece of artistic design, the Italian design shown is most exquisite, and most of the English lighthouses are splendid in their simplicity. The American lighthouses on the other hand are usually of such extreme simplicity, as to be very often actually forbidding in appearance. Stone water towers and others on land, will usually carry more ornamentation than has been indicated for light towers, but most



Suspension Bridge Tower Australia

designers will agree that too ornate details or any bizarre features should be avoided, if the most pleasing results are to be attained.

The design of steel towers remains to be developed along the lines already indicated, as none of those built for purely utilitarian purposes, have approached in any degree the beauty of the Eiffel Tower. However it is seldom that decorative ornament can be applied to steel towers, except the towers of suspension bridges, with any degree of success, and the general design should therefore have much thought expended upon it, so that steel towers for whatever purposes they are to be used, may at least be inherently beautiful.

The simplicity necessary for the design of retaining walls, need not be such as to render them unpleasing, and ornamentation may be applied to make them more artistic, whenever the expense is not a final deterrent. The improvements possible in the ornamentation of dams should always be most carefully considered, as the small percentage so added to the total cost of a great dam, makes that feature negligible when the great artistic good which results is fully considered. The great dams are being more and more visited by tourists, but they are not so constantly viewed as are the tunnel portals on the lines of the railways, and yet their artistic design has also been almost entirely neglected. The design of such a portal must perforce be along very simple lines, as the use of any considerable decoration would usually be out of harmony with the purpose and environment. Both dams and tunnel portals are most frequently located in the mountains, so in order to have them harmonize with the surroundings, they must be of a massive and monumental character, but this does not require them to be unpleasing in appearance, and the designer may frequently find means for decorating them in an appropriate and harmonious manner.

The design of power houses is on the dividing line between engineering and architecture, and in many instances the owners will insist on a specialist being called into consultation. However the engineer must perforce as already stated, design the foundations, make the layout for placing the machinery, plan the traveling cranes, the steel roof, and at least decide upon the character of the walls, which may be of monolithic

concrete or brick curtain walls between steel columns. Naturally when such is the case, with the power house located somewhat remote from civilization, the engineer has most often designed and executed the entire structure, but in a very plain and almost unpleasing manner. The purpose of the author is to point out that such structures and all others may be made monumental and at least pleasing, if the engineer has had education and training in engineering architecture.

> "All are architects of fate,
> Building in these walls of time.
> Some with massive deeds and great,
> Some with ornaments of rhyme.
>
> "Nothing useless is, or low,
> Each thing in its place is best,
> And what seems but idle show,
> Strengthens and supports the rest."

BUONARROTI, Michelangelo, (1475-1564). The great Florentine poet, artist, sculptor, architect, and engineer, and a contemporary of Leonardo da Vinci, who was even more varied in his genius. Michelangelo's great paintings like those in the Sistine Chapel are well known; his work as chief architect of St. Peter's church; and engineering works like the Bridge of the Rialto in Venice.

EIFFEL, Alexandre Gustave, (1832-1923). The famous French builder of bridges, and who designed and built the great Eiffel Tower for the French Exposition of 1889, and which is described in the chapter on Steel Towers. The structure is as yet the tallest in the world, and except the designing of the locks for the De Lesseps Panama canal, is his chief work of great note.

FOWLER, Sir John, (1817-1898). The noted English Engineer began as a pupil of John Leather, on surveys and canals; then on many railways and notable bridges, including the Forth Bridge on which he was joint engineer with Sir Benjamin Baker; and did much work in Egypt for the Khedive Ismail.

LESSEPS, Ferdinand De, (1805-1894). Noted French Diplomat and constructor of the Suez Canal which was completed and opened under Napoleon III in 1869 or on one hundredth anniversary of the birth of Napoleon I, who made the first surveys for it when in Egypt. De Lesseps undertook the digging of the Panama Canal, but seriously underestimated the difficulty.

LINDENTHAL, Gustav, (1850-). The noted bridge engineer, began in Austria and Switzerland. Was engineer of the Philadelphia Centennial Exposition from 1874 to 1877; constructed numerous notable bridges in the United States, including the great Sciotoville continuous girder over the Ohio River; the great Hell Gate arch at New York City; and plans for a mammoth suspension bridge of 3240 feet span over the Hudson River.

NOBLE, Alfred, (1844-1914). The distinguished American engineer, designed and carried out notable works of many kinds. He was a member of the Nicaragua Canal Board; of both Panama Canal Commissions; of the Galveston Sea-wall Board; head of the Pennsylvania R. R. Long Island Tunnel staff; consulting engineer of the Canadian Welland Canal; and connected with numerous great bridge projects, as well as other engineering works.

PEGRAM, George Herndon, (1855-). The Chief Engineer of the Interborough Rapid Transit Company of New York, began his bridge work as principal assistant to C. Shaler Smith; was Chief Engineer of the Edge Moor Bridge Works for many years; Chief Engineer of the Union Pacific Railway; built the St. Louis Union Station; designed the Kansas City Elevated Railway; invented the Pegram bridge truss; and built numerous notable bridges and engineering works.

PERRONET, Jean Rodolphe, (1708-1794). The famous French engineer who was Chief Engineer des Ponts et Chaussees prior to Napoleon's reign. He was a playmate of Louis XV when a boy, and enjoying his favor became the leading engineer of his time on all classes of public works, including the famous Pont de la Concorde in Paris; originating many useful engineering processes.

RENNIE, John, (1761-1821). The builder of three great bridges over the Thames at London, the Waterloo Bridge, the Southwark Bridge, and London Bridge. He did not live to see the last completed under his son John. The many notable canals and harbors built by him indicate his versatility and proficiency. The London Docks, and East India Docks, as well as the great Plymouth Breakwater, are outstanding examples of his work.

ROEBLING, JOHN AUGUSTUS, (1806-1869). The builder of the Brooklyn Bridge, as well as those at Cincinnati, Pittsburgh, and Niagara was a Prussian engineer, all of whose great work was done in the United States, was one of those daring spirits to whom we owe the great progress of the world. The wire from his works was used on the Manhattan, Williamsburg, and 178 Street Bridges in New York.

SMEATON, John, (1724-1792). Began as a mathematical instrument maker, and made many improvements on navigation and astronomical instruments. In 1759 he received the Copley medal from the Royal Society for his paper on Experiments on Water and Wind Mills. He was widely engaged as engineer on canals, and built the second Eddystone lighthouse. His last years were much devoted to astronomical observations and studies.

SMITH, Charles Shaler, (1836-1886). The builder of the great Lachine Bridge over the St. Lawrence River, and the High Bridge over the Kentucky River, is certainly the dean of American bridge engineers. His book the Sabula Draw by Graphics, and his studies of wind pressure on structures are among his best known contributions to engineering. The many of his assistants who became famous, have greatly added to his fame.

STEPHENSON, George, (1781-1848). Was a colliery engineer at Wylam near Newcastle, and at seventeen he could not read. He made remarkable progress at a night school, stimulated by a desire to obtain information about the inventions of Boulton and Watt. He constructed his first travelling engine the "My Lord" in 1813, and in 1822 succeeded in convincing the projectors of the Stockton and Darlington railway to use steam engines in place of horses. This and many other railways were built with the aid of his son Robert.

STEPHENSON, Robert, (1803-1859). The son of George Stephenson, is usually considered the coinventor with his father, of the railway. His career covered engineering works of magnitude all over the British Empire, but he is best known for his Britannia Bridge over Menai Straits, and the great Victoria Bridge over the St. Lawrence at Montreal, Canada, where new spans have been built on the original piers. The original Menai Bridge built about eighty years ago, is still used for high speed trains.

TELFORD, Thomas, (1757-1834). The English engineer who is well known for the form of road which bears his name. Like others of his contemporaries he was very versatile, and engaged in many branches of engineering. The Menai Straits Suspension Chain Bridge is his most notable work, and with one hundred years of use and slight modifications it is still carrying traffic. The heavy stone towers and approaches will outlast the centuries.

THACHER, Edwin, (1840-1920). The inventor of the slide rule which bears his name, the Thacher truss, and of a system of reinforced concrete bridges, was one of the most noted of bridge mathematicians and designers, and built many large and important bridges all over the continent. Several of the reinforced concrete bridges designed by him are described in the foregoing pages.

Masonry Construction - - - - - - Baker
History of Architecture - - - - Banister Fletcher
Seven Wonders of the Ancient World - - - Banks
Architecture and Democracy - - - - Bragdon
Dictionary of Engineering - - - - - Byrne
Encyclopaedia of Civil Engineering - - - - Cresy
American Architecture of Today - - - - Edgell
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Endurance and Beauty in Steel Bridges - - - Fowler
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Engineering and Building Foundations - - - Fowler
Sub Aqueous Foundations - - - - - Fowler
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